International Journal of Pediatrics

Exercise in Children during Health and Sickness

Guest Editors: Mutasim Abu-Hasan, Neil Armstrong, Lars B. Andersen, Miles Weinberger, and Patricia A. Nixon

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Editorial Board

Contents

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Editorial

Exercise in Children during Health and Sickness

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Because of the rapidly increasing prevalence of obesity among children worldwide and the realization that this global epidemic is closely related to changing life style, especially relating to diet and exercise, research in the effects of exercise on children's health and the effects of children's health on their ability to exercise becomes timely and imperative. Promoting scientific researching in the field of exercise medicine in children has therefore been the primary motive behind this special issue of the International Journal of Pediatrics which is dedicated to publishing important works in the field.

To the great satisfaction of our team of editors, a great number of good quality research results were submitted to the issue from all four corners of the world which indicates a strong interest in this very important field of medicine worldwide.

The first section of this issue contains cross-sectional population studies that provide evidence confirming the strong correlation between obesity and lack of activity in children of different populations and different age groups (the first, second, and third papers). Furthermore, a 12-month interventional study from Sweden showed that longer exercise periods performed by school age boys resulted in more muscle mass and increased muscle strength (the fourth paper).

The second section of the issue contains several articles studying the different genetic, environmental, parental, and other psychosocial factors that can potentially affect children's level of exercise activity. These articles collectively provide evidence for the variety and complexity of factors that affect children's predilection or exercise (the fifth, sixth, seventh, and eighth papers). They also identify potential areas for future intervention to promote exercise early in life (the ninth paper). One example of such opportunities involves the use of video gaming. Even though the overuse of video gaming has been largely blamed for the decreasing level of physical activity in children, the case might be completely reversed with the recent advent of interactive video gaming which tends to be preferred by children over conventional video gaming and is associated with higher level of physical activity (the tenth paper).

The third section deals with research relating to exercise in children with known chronic illness such as diabetes, cystic fibrosis, neuromuscular diseases, arthritis, and congenital heart diseases with emphasis not only concerning the limitations these illnesses impose on children's ability to exercise and become physically fit but also on how increased fitness in these patients can modulate their disease process and therefore on ways exercise can be performed and promoted (the eleventh, twelfth, thirteenth, fourteenth, fifteenth, and sixteenth papers)

The fourth section discusses hemodynamic responses to exercise in children as compared to adults (the seventeenth paper) and explores the hormonal and inflammatory profile of overweight and normal weight children and relates them to cardiovascular fitness (the eighteenth paper).

The fifth and final section has one article which evaluates the validity of different accelerometeric measurements used in exercise research to objectively grade level of physical activity as compared to the gold standard of directly measuring energy expenditure (the nineteenth paper)

We hope that this special issue will contribute substantially to the existing body of knowledge of this new and growing field of exercise medicine in children and to stimulate further needed research.

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Research Article

Dietary Intake and Physical Activity of Normal Weight and Overweight/Obese Adolescents

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Purpose. To evaluate the relationship between overweight/obesity and dietary/lifestyle factors among Italian adolescents. *Methods*. On a total of 756 adolescents with mean age 12.4 ± 0.9, body mass index, food consumption, and time dedicated to after school physical activities and to TV viewing were determined. The data were analysed according to age, nutritional status, and gender. The analysis of variance and multiple logistic regression analysis were performed to investigate the association between dietary/lifestyle factors and overweight/obesity. *Results*. The percentages of overweight and obesity were, respectively, 28% and 9% among boys, 24% and 7% among girls. The overweight/obesity condition in both genders was associated with parental overweight/obesity ($P < .001$ for mother), less time devoted to physical activity ($P < .001$ for boys and $P < .02$ for girls) and being on a diet ($P < .001$). Direct associations were also observed between BMI and skipping breakfast and the lower number of meals a day (boys only). *Conclusions*. This pilot study reveals some important dietary and lifestyle behaviour trends among adolescents that assist with identification of specific preventive health actions.

1. Introduction

Obesity is considered one of the most remarkable medical and social problem in western societies. In particular, childhood obesity is rapidly emerging as a global epidemic with a great variation in secular trends across countries [1, 2]. It is estimated that in the near future over 26 million children in the European countries will be overweight or obese [3]. This trend will have profound public health consequences since obese children tend to become obese adults [4, 5]. A review of the literature related to the years 1970–1992 revealed that 42–63% of obese children in the USA have become obese adults [6]. Childhood obesity is associated with a plethora of psychosocial disorders [7] and health risks including cardiovascular disease risk factors [8, 9].

In Italy, the National Institute of Research on Food and Nutrition (INRAN) carried out with the collaboration of local public institutions a survey to assess the prevalence of overweight and obesity among 8–10 years old children of 6 regions distributed from North to South during the years 2000–2002. The study demonstrated that 23.9% of children were overweight and 11.1% of the sample were obese [10], highlighting one of the highest prevalence in the European countries [11]. The distribution of obesity was not homogeneous, showing a higher prevalence in the Southern areas compared to that of the Northern areas. Such trends were confirmed by the results of the national survey carried out recently on children of the same age and that showed the following prevalence of overweight and obesity: 23.6% and 12.3% [12]. Paediatric obesity in European countries is a common problem and studies were performed to identify risk factors and action plans for obesity prevention and treatment [11, 13–15].

The aetiology of obesity is extremely complex, and it is generally linked to many factors that are not only of genetic type. Most of the time personal lifestyle choices as well as cultural, environmental, and behavioural factors, significantly influence obesity [16, 17]. Research findings have shown that many dietary habits are highly correlated to obesity, and physical activity or other lifestyle behaviours are important covariates [18]. They are considered "universal" risk factors for overweight youth [19] and are identified in the increasingly toxic and obesogenic environments of our societies, specially of developed countries, although their relative causal significance is not well understood [20, 21].

In particular, the eating habits of Italian school aged children and adolescents are involved in a changing process from the more traditional Mediterranean diet, to more westernized eating models, rich in animal proteins, fat, and with low intake of complex carbohydrates and fiber [22–24]. This, together with a decrease in energy expenditure, probably, contributes to the increase of the obesity prevalence [15, 25]. However, most of the studies performed in Italy on school children focused on the estimation of the prevalence of overweight and obesity [11, 12] or on the estimation of the average food and nutrient intakes [22, 23]. The purpose of the present pilot study was to provide data on the association of paediatric overweight and obesity with possible risk factors.

2. Materials and Methods

In the years 2004/2006, we studied 756 adolescents (391 males and 365 females), mean age 12.4 ± 0.9, belonging to three public middle schools of a Roman urban area. All students of the selected schools were enrolled on a voluntary basis. Prior to their acceptance, the adolescent's parents or others caregivers were fully informed about the objectives and methods of the study and signed a consent form which included self-reported weight and height and children's weight at birth and if the child had been or not breastfed. The participation rate was 88%. For each student anthropometric, lifestyle and dietary data were collected. Height and weight were measured in triplicate in the school setting, in the morning according to WHO international guidelines [26]. The average of the three measurements was used in the analyses. Weight was measured in underwear by a regularly calibrated battery-operated digital scale (SECA 8129) to the nearest 0.1 kg; height was measured by a portable stadiometer (Promes) to the nearest 0.1 cm. To assess levels of overweight and obesity, we used International Obesity Task Force (IOTF) cut offs [27]. We used BMI because it can be at group level an appropriate index to define overweight in children and adolescents [28]. Information concerning the time dedicated to organized sport activities and to other after school physical activities such as running, jumping, bicycle riding, or playing soccer, and the estimation of the time spent at the computer or watching TV were obtained by means of a questionnaire by an in-depth interview to the students during the anthropometric measurement sessions. The physical activity questions were based on those used for the validated adolescent physical activity recall questionnaire, to investigate on organized sport and nonorganized physical activity out of school and during weekends [29]. The sedentary activity questions we adopted match the ones of the validated adolescent sedentary activity questionnaire [30, 31]. The dietary assessment was based on a 24-hour dietary recall assisted by food records: this method is considered adequate when sample size is sufficiently large [32]. The food questionnaire was delivered to students in the morning at school. The delivery of the "form" was the occasion to gather through recall data on the last meal consumed (breakfast) and for training the adolescents in advance on how to keep complete and accurate records of all food and beverages as they were consumed through the day, without quantification of the portion size. This food registration served solely as a memory prompt during the recall [33] conducted by well trained and standardized dieticians the day after. During the face-to-face interview, the dietician estimated the amount of each food eaten, with the assistance of a visual support that reported standard household measures or portions of the common Italian foods [34]. Another task of the dietician was to collect further details about recipes, food description, preparation practices, and information about students being or not on a diet. The calendar of the food survey was organized in order to represent an adequate proportion of weekdays and weekend days.

Dietary data were carefully checked and entered by interviewers into a nutrition software system INRAN-DIARIO 3.1 developed by INRAN. This system translates the amount of food eaten into individual energy and macronutrients and assigns consumed foods into food groups and subgroups.

3. Statistical Analysis

The BMI values were initially recoded into three categories: normoweight, including underweight and normal weight children (the number of underweight children was very small), overweight, and obese.

Associations between overweight status and physical/sedentary activities (sports activities outside of school, hours of sports activities, hours of playing outside of home, hours of watching TV), lifestyle characteristics (eating breakfast, number of meals per day, being on a diet), energy and macronutrients intakes, and other information (birth weight, breastfeeding, overweight/obesity status of mother and father) were also investigated. Only two categories of BMI values were considered to study these associations, namely, normoweight and overweight, arranging overweight and obese in a single category. The associations between BMI categories and each numerical variable were tested by the Kruskal-Wallis test, while the chi-square test evaluated the associations with categorical variables. All reported probability values (P values) were compared to a significant level of .05. Multiple logistic regression [35, 36] was used to estimate the relationship between students' food habits, lifestyle, and other information, and their likelihood of being overweight by calculating the odds ratios (OR) and the corresponding 95% confidence intervals (CI*s*); P values associated with tests for linear trend in the OR were also provided. A first logistic regression model evaluated to what extent the intakes of different food categories were associated with overweight status. For this purpose, tertiles of food intake were calculated for each distribution and the levels of each food item were recoded into *low* consumption if lower

Table 1: Prevalence of normoweight, overweight and obesity in boys and girls.

Boys Age (years)		Body Mass Index (kg/m^2) Mean ± SD	Body Mass Index Categories Normoweight	Overweight	Obese
10-11	($n = 97$)	19.4 ± 3.1	72%	24%	4%
12	($n = 146$)	21.6 ± 4.3	54%	32%	14%
13	($n = 120$)	21.5 ± 3.7	65%	28%	7%
14–17	($n = 30$)	21.3 ± 3.5	70%	27%	3%
Total	($n = 391$)	21.0 ± 3.9	63%	28%	9%
Girls Age (years)		**Body Mass Index (kg/m^2) Mean ± SD**	**Body Mass Index Categories Normoweight**	**Overweight**	**Obese**
10-11	($n = 104$)	20.1 ± 3.5	61%	34%	5%
12	($n = 133$)	21.1 ± 3.7	68%	23%	9%
13	($n = 107$)	21.3 ± 3.7	76%	18%	6%
14–17	($n = 21$)	21.3 ± 2.6	81%	19%	—
Total	($n = 365$)	20.9 ± 3.7	69%	24%	7%

or equal to the inferior tertile, *medium* if between the inferior and the superior tertile, and *high* if equal or higher than the superior tertile. OR and associated 95% CI are presented for each level of the variables in comparison with the *high* referent level.

Correlation of each food group with other food groups entered in the model was calculated and the presence of high multicollinearity was excluded. A second logistic regression model evaluated to what extent lifestyle characteristics, energy and macronutrients intakes, birth weight, breast-feeding, being on a diet and parent BMI were associated with overweight status. The number of meals per day was recoded into three categories: *2-3*, *4-5,* and *6-7*. Hours of sports and hours of watching TV were both recoded into two categories (*0–3* and *more than 3, 0–2* and *more than 2,* resp.). Both mother's and father's nutritional status were recoded into *normoweight* (including underweight and normal) and *overweight* (including obesity). Tertiles of distribution were calculated for total daily energy, fats, proteins, and carbohydrates intakes and the levels were recoded into *low*, *medium,* and *high* as described above for food intake.

Variables that showed an association with BMI status in the previous univariate analysis were included in the models, some other independent variables were included through forward selection. All statistical analyses were carried out using the software SAS for windows [37].

4. Results

Table 1 presents the distribution of BMI categories by age, stratified by gender. Overall, 28% of the boys and 24% of the girls were overweight; 9% of boys and 7% of girls were obese. Overweight/obesity status showed high rates in 12 and 13 aged boys while it tended to decrease with age in the girls group.

Table 2 summarizes the variables investigated in relation to weight status. Fewer overweight boys played sports outside of school compared with normoweight ones; moreover, overweight students of both genders spent less time in sport activities with respect to the normoweight ones; overweight girls spent more time watching TV; overweight boys ate a little less frequently (4.5 meals a day) than the normoweight ones (about 5 meals a day); fewer overweight boys regularly ate breakfast and more overweight students of both genders were on a diet compared with normoweight subjects. More overweight boys and girls had overweight mother and father compared with the normoweight ones. Overweight boys and girls showed lower intakes of total energy and macronutrients (fat, protein and carbohydrates) than normoweight ones.

Table 3 reports the mean consumption levels of several food categories in relation to children overweight status. Overweight boys reported lower consumption of bread, pasta, salt bakery, milk and yoghurt, sugar-sweetened drinks and sweets, chocolate and jam compared to normoweight ones; overweight girls reported lower consumption of milk and yoghurt compared to normoweight girls.

Results of the logistic regression examining the associations between overweight and food consumption habits are presented in Table 4. The tertiles of intake for each food group entered in the model are reported in Table 5. There was a negative association ($P < .05$) between bread and pasta intake and BMI in boys such that those presenting low and medium level of bread intake were, respectively, 2.76 and 2 times as likely to be overweight than boys presenting high bread intake; similarly, boys presenting low and medium level of pasta intake were, respectively, 1.83 and 2.45 times as likely to be overweight than those presenting high pasta intake. There was a negative relationship between overweight condition and the intake of salt bakery and milk and yoghurt in both genders such that with decreasing consumption there were greater odds of being overweight; similarly, with decreasing intake of meat and meat product (boys only), cheese and eggs (girls only), sugar-sweetened drinks, and sweets chocolate and jams (boys only), there were greater odds of being overweight.

There was a positive association between the overweight status of students and their parents' BMI (Table 6), such that

Table 2: Variables investigated in relation to weight status.

	Boys		Girls	
	Normoweight	Overweight	Normoweight	Overweight
Sports activities outside of school, %	80*	68	76	71
Hours of sporting activities, mean ± sd	4.2 ± 3.3**	3.0 ± 2.7	3.0 ± 3*	2.6 ± 2.4
Hours of playing activities outside of home, mean ± sd	5.8 ± 5.4	7.0 ± 6.8	5.0 ± 4.5	6.0 ± 5.7
Hours of watching TV, mean ± sd	2.8 ± 1.4	2.5 ± 1.3	2.4 ± 1.4*	2.7 ± 1.3
Overweight status of mother, %	21**	37	18**	49
Overweight status of father, %	48*	62	50*	68
Birth weight, mean ± sd	3.3 ± 0.6	3.3 ± 0.6	3.2 ± 0.5	3.2 ± 0.5
Breastfeeding, %	73	76	75	73
Eating breakfast, %	89*	77	85	79
Number of meals per day, mean ± sd	4.8 ± 0.7**	4.5 ± 0.8	4.8 ± 0.6	4.7 ± 0.7
Being on a diet, %	3**	29	7**	27
Energy intake, mean ± sd				
(kJ/day)	11608 ± 3888**	10097 ± 3201	9394 ± 2421*	8654 ± 2202
(kcal/day)	2773 ± 929**	2412 ± 765	2244 ± 578*	2067 ± 526
Fat intake (g), mean ± sd	117 ± 46*	105 ± 37	99 ± 32*	89 ± 32
Protein intake (g), mean ± sd	105 ± 39*	94 ± 33	86 ± 27*	80 ± 24
Carbohydrates intake (g), mean ± sd	346 ± 123**	293 ± 104	272 ± 77	253 ± 70

*$P < .05$ (when compared with the overweight group)
**$P < .001$ (when compared with the overweight group).

Table 3: Consumption of food categories (g/day/per capita, mean ± sd).

	Boys		Girls	
	Normoweight	Overweight	Normoweight	Overweight
Bread	108.7 ± 99*	90.4 ± 83	82.1 ± 69.7	78.4 ± 67.5
Pasta	82.0 ± 62*	64.7 ± 49.3	66.6 ± 59.1	58.6 ± 57.3
Rice	10.6 ± 35.4	14.1 ± 38.2	9.9 ± 31.4	8.4 ± 26.1
Potatoes	58.1 ± 92.9	53.9 ± 98.8	61.4 ± 91.7	54.2 ± 89.7
Salt bakery	70.4 ± 104.7*	55.4 ± 110.9	46.6 ± 75.1	46.8 ± 77.4
Sweet	49.9 ± 55.6	39.8 ± 50.2	41.5 ± 53.2	36.0 ± 42.9
Breakfast cereals	4.7 ± 11.1	3.6 ± 10.5	3.9 ± 10.7	5.8 ± 13.3
Legumes	13.7 ± 36.5	11.5 ± 29.5	11.5 ± 29	9.1 ± 27.3
Vegetables	174.8 ± 124.4	171.3 ± 129.6	148.7 ± 105.9	136.4 ± 115.4
Fresh fruits	131.2 ± 141.5	115.5 ± 138.9	127.8 ± 132	125.5 ± 145.7
Meat and meat products	173.3 ± 123.3	148.0 ± 97.2	149.7 ± 101.4	147.4 ± 99.4
Poultry	47.0 ± 88.6	51.3 ± 90.1	38.3 ± 66.9	51.7 ± 78.8
Fish and seafood	29.4 ± 79.5	36.0 ± 95.2	18.2 ± 47.5	17.8 ± 47.1
Milk and yoghurt	244.9 ± 199.8**	168.9 ± 156.1	197.1 ± 162.4*	155.8 ± 154.7
Cheese	49.2 ± 61.6	56.5 ± 62.9	41.8 ± 53.3	35.5 ± 56.6
Eggs	23.7 ± 39.9	23.7 ± 37.4	22.0 ± 38.9	17.2 ± 34.8
Snacks and potato crisps	4.7 ± 14.8	5.6 ± 22.9	5.5 ± 17.4	4.9 ± 12.7
Sugar-sweetened drinks	301.6 ± 297.8*	237.3 ± 297	183.6 ± 232.4	188.4 ± 234.8
Sweets, chocolate and jam	28.2 ± 33.9**	14.7 ± 20.2	20.0 ± 25.2	19.0 ± 23.5

*$P < .05$ (when compared with the overweight group)
**$P < .001$ (when compared with the overweight group).

Table 4: Food consumption in relation to overweight status: results of multiple logistic regression.

		Odds ratio	95% confidence limits		*P*
Boys	Bread (low versus high)	**2.76**	1.50	5.01	**.001**
	Bread (medium versus high)	**2.00**	1.11	3.57	**.02**
	Pasta (low versus high)	**1.83**	1.03	3.26	**.03**
	Pasta (medium versus high)	**2.45**	1.38	4.38	**.002**
	Salt bakery (low versus high)	1.55	0.76	3.18	.226
	Salt bakery (medium versus high)	**2.38**	1.37	4.11	**.002**
	Breakfast cereals (low versus high)	0.67	0.33	1.35	.266
	Meat and meat products (medium versus high)	**2.15**	1.22	3.78	**.008**
	Milk and yoghurt (low versus high)	**2.36**	1.28	4.35	**.005**
	Cheese (low versus high)	0.65	0.36	1.18	.157
	Eggs (low versus high)	0.70	0.36	1.36	.295
	Sugar-sweetened drinks (low versus high)	2.20	1.25	3.86	**.006**
	Sweets, chocolate and jam (low versus high)	**2.81**	1.58	5.01	**<.001**
	Sweets, chocolate and jam (medium versus high)	**2.05**	1.13	3.72	**.01**
Girls	Bread (low versus high)	0.97	0.52	1.81	.929
	Bread (medium versus high)	1.65	0.89	3.07	.111
	Pasta (low versus high)	1.46	0.81	2.64	.208
	Pasta (medium versus high)	0.70	0.37	1.30	1.325
	Salt bakery (low versus high)	**1.87**	1.02	3.43	**.04**
	Salt bakery (medium versus high)	1.41	0.71	2.78	.325
	Breakfast cereals (low versus high)	0.37	0.19	0.76	.067
	Meat and meat products (medium versus high)	1.07	0.58	1.95	.833
	Milk and yoghurt (low versus high)	**2.42**	1.24	4.71	**.009**
	Cheese (low versus high)	**2.28**	1.22	4.26	**.009**
	Eggs (low versus high)	**1.98**	1.08	3.63	**.03**
	Sugar-sweetened drinks (low versus high)	0.64	0.34	1.19	.159
	Sweets, chocolate and jam (low versus high)	1.16	0.63	2.13	.641
	Sweets, chocolate and jam (medium versus high)	0.72	0.39	1.30	.270

boys with a normoweight mother and father were 0.50 times as likely to be overweight than those with overweight parents; girls with normoweight mother were 0.20 times as likely to be overweight than those with overweight mother, and girls with normoweight father were 0.50 times as likely to be overweight than those having overweight father. There was a negative association between carbohydrates intake and BMI in boys such that those with low intake were 2.5 times as likely to be overweight as those with high intake. No significant associations were found between BMI categories and physical activities, lifestyle characteristics, levels of energy, fat and protein intakes.

5. Discussion

The results show a high prevalence of overweight and obesity in the group of adolescents studied. In particular, the mean overweight/obese rates were 37% in boys and 31% in girls with a trend to increase with age in boys (28% at 11 years and 30% at 14–17 years) and to decrease in girls (39% at 11 years and 19% at 14–17 years). The trend of prevalence of overweight/obesity in Roman adolescents reaffirms what other authors have observed in similar population groups [38, 39]. However, the prevalence rates are quite high and underscore the need for public health campaigns aimed at preventing and reducing overweight and obesity in Roman youth.

In this study, overweight status was associated with decreased physical participation (Table 2), highlighting the role that physical activity plays in the childhood obesity epidemic. Time dedicated to sporting activities is significantly higher in normoweight males and females. These results are consistent with the growing body of evidence implicating sedentary activities as one of the leading factors in adolescent overweight [40, 41]. Moreover, our findings showed also associations for hours of television viewing but

Table 5: Nutrients and food categories' tertiles of consumption (g/day/per capita).

	Inferior tertile	Superior tertile
Energy intake (kJ)	8639.5	10915.2
Fat intake (g)	85.9	114.4
Protein intake (g)	77.7	101.4
Carbohydrates intake (g)	250.5	320.9
Bread	45	112.8
Pasta	46.8	89.2
Salt bakery	0	50
Breakfast cereals	0	1.2
Meat and meat products	102.4	187.3
Milk and yoghurt	124.5	251.6
Cheese	6.8	54.6
Eggs	0	14.7
Sugar-sweetened drinks	7.8	250
Sweets, chocolate and jam	0	23

for girls only, and for sporting activities outside of school for boys only. Strong direct association was also observed between overweight of mother and father and their children, confirming the results of other studies [42, 43]. Regarding birth weight, Hirschler et al. [44] have shown that a high birth weight is linked to a higher risk of becoming obese during childhood, but in our study no relationship was observed between these two variables. As far as breastfeeding is concerned, we did not observe any association with obesity risk reduction; however, since we did not collect information about the duration of breastfeeding, this could be a limit. Nevertheless, on this issue there are contrasting data in the literature [45, 46].

We observed in normoweight subjects a more common habit to have breakfast, but the association is statistically significant only for boys. Our findings could be in accordance with the growing body of evidence supporting the role of this meal in decreasing body weight [47]. Breakfast skipping can lead to overeating later in the day, as it was shown by a study conducted in young healthy men [48]. The result showed the lower frequency of meals consumed associated with the prevalence of overweight status in males, and this agrees with that of other investigators who showed that adolescents with a consistent meal pattern were leaner than those with an inconsistent one [49]. However, this aspect is still controversial [50, 51].

In the present study, the percentage of overweight adolescents who stated to be on a diet is high and it is statistically significant ($P < .001$) when compared with normoweight boys and girls of the same age.

We found a negative relationship between energy, macronutrients intakes, and BMI, so that such consumptions were surprisingly higher in normoweight adolescents, than overweight ones, especially in boys. Different motivations can be addressed to support these results. First, although the normal subjects eat more than overweight students, they have also higher physical activity levels with possible consequent higher energy expenditure [52]. Second, a significant difference resulted in this study between adolescents being on a diet and not being on a diet; 29% and 27%, respectively, of overweight boys and girls reported to be on a diet versus only 3 and 7% of the normoweight ones. Presumably the subjects on a diet had reduced food consumption during the period of the dietary recall. Moreover, as observed in other studies, obese individuals tend to underestimate their food intakes and overestimate their physical activity patterns [53].

Possible underreporting of the studied subjects was preliminary assessed using the criteria defined by Goldberg et al. [54]. The resting metabolic rate (RMR) for each subject was calculated using the prediction equation developed by Commission of the European Communities [55] (RMR[MJ/day] for boys $= 0.068 * \text{weight [kg]} + 0.57 * \text{height [m]} + 2.16$; RMR[MJ/day] for girls $= 0.035 * \text{weight [kg]} + 1.95 * \text{height [m]} + 0.84$) [56]. The percentage of possible underreporters was almost similar in both normal and overweight. Besides, the mean energy intake was lower in overweight non-underreporting subjects than in normoweight ones. Several food groups' mean intake was lower in overweight/obese than in normoweight non-underreporting subjects showing almost the same results observed in the whole group of subjects. These outcomes suggested not to exclude the possible underreporters from the present analysis.

Changes in dietary patterns in the past few decades, such as an increase in the consumption of high fat and sugar foods, have been also implicated in the increase in obesity [2]. Indeed, in the present study the consumption of food categories or single food items was almost always higher in normoweight boys and girls and it was particularly higher for "milk and yoghurt" (Table 3). In this study, a low "milk and yoghurt" daily consumption was associated with overweight status; this result is on line with several epidemiologic studies where an inverse association has been found between milk and dairy consumption and risk of being overweight [57]. There is an increasing body of literature suggesting that dairy calcium may play a role in maintaining stable body weight [58].

Intake of sugar-sweetened drinks was lower in overweight adolescents. On this matter, evidence implicating a high intake of soft drinks in promoting weight gain is still controversial [59]. Most of our overweight adolescents were on a diet and this could justify the lower consumption of most food items, including sweetened beverages.

The multiple logistic regression analyses of food consumption behavior of boys and girls in relation to overweight status confirmed some of the associations found through the analysis of variance. Boys with a low/moderate consumption of bread, pasta, meat and meat products, sweets, chocolate and jam show a higher tendency towards overweight status with respect to the subjects with high consumption. In both genders, the tendency towards being overweight grows with decreasing intakes of salt bakery and milk and yoghurt. As previously observed, such trends could be explained with the tendency of overweight subjects to be on a diet.

Table 6: Lifestyle characteristics and other information in relation to overweight status: results of multiple logistic regression.

		Odds ratio	95% confidence interval		*P*
Boys	Sports activities outside of school (*yes* versus *no*)	0.73	0.36	1.45	.371
	Hours of sporting activities (*0–3* versus *more than three*)	1.35	0.74	2.46	.325
	Hours of watching TV (*0–2* versus *more than two*)	1.31	0.82	2.10	.255
	Overweight status of mother (*normoweight* versus *overweight*)	**0.55**	0.33	0.94	**.029**
	Overweight status of father (*normoweight* versus *overweight*)	**0.57**	0.36	0.93	**.024**
	Eating breakfast (*yes* versus *no*)	0.65	0.32	1.32	.232
	Number of meals per day (*2-3* versus *6-7*)	2.57	0.76	8.68	.127
	Number of meals per day (*4-5* versus *6-7*)	1.64	0.77	3.47	.20
	Energy intake (kJ) (*low* versus *high*)	0.89	0.25	3.22	.864
	Fat intake (g) (*low* versus *high*)	1.16	0.43	3.12	.764
	Protein intake (g) (*low* versus *high*)	1.22	0.49	3.09	.668
	Carbohydrates intake (g) (*low* versus *high*)	**2.53**	1.09	5.86	**.029**
Girls	Sports activities outside of school (*yes* versus *no*)	1.02	0.54	1.94	.105
	Hours of sporting activities (*0–3* versus *more than three*)	1.66	0.90	3.08	.071
	Hours of watching TV (*0–2* versus *more than two*)	0.79	0.47	1.35	.394
	Overweight status of mother (*normoweight* versus *overweight*)	**0.24**	0.14	0.41	**<.0001**
	Overweight status of father (*normoweight* versus *overweight*)	**0.50**	0.30	0.85	**.009**
	Eating breakfast (*yes* versus *no*)	0.94	0.47	1.89	.859
	Number of meals per day (*2-3* versus *6-7*)	1.13	0.24	5.30	.876
	Number of meals per day (*4-5* versus *6-7*)	0.76	0.33	1.73	.512
	Energy intake (kJ) (*low* versus *high*)	0.96	0.19	4.83	.962
	Fat intake (g) (*low* versus *high*)	1.27	0.38	4.26	.698
	Protein intake (g) (*low* versus *high*)	1.04	0.42	2.59	.933
	Carbohydrates intake (g) (*low* versus *high*)	2.19	0.72	6.67	.167

Parental obesity can be a significant factor predicting the development of obesity in children [42]. Whitaker and colleagues have reported that parental obesity increased the risk of childhood obesity by twofold to threefold at all ages, most likely because the influence of parental obesity is the result of a mixture of genetic and environmental influences.

A positive correlation between adiposity of children and parents was observed, confirming the results obtained by the logistic regression analysis; in particular the tendency towards overweight was 50% lower for students having normoweight father (both genders) and mother (boys only) with respect to those with overweight parents.

6. Conclusions

In conclusion, the results of this pilot study on adolescents showed a high percentage of overweight/obesity. Such nutritional status in both genders was associated with parental obesity, low physical activity level, and being on a diet. The possible consequence of being on a diet is the lower consumption in overweight students of most food groups compared to normal weight subjects. Moreover, direct associations were observed between BMI and the more common habit to skip breakfast and a reduced meal frequency (boys only).

From the study emerged some critical features related to the dietary profile and lifestyle of the Roman normal and overweight adolescents studied. It is our intention to deepen and broaden the investigation in order to provide further data useful for identifying specific and preventive public health actions.

Competing Interests

The authors declare that they have noncompeting interests.

Authors' Contributions

D. D'Addesa conceived, coordinated, participated in the design of the study and drafted the manuscript. L. D'Addezio conceived and performed the statistical analysis and contributed to draft the manuscript. D. Martone participated in the design of the study and to the collection of data. L. Censi conceived and participated in the design of the study and coordinated the collection of anthropometric data. A. Scanu participated to the gathering of nutritional data. G. Cairella participated in the design of the study and to the selection of the studied subjects. A. Spagnolo contributed to perform the statistical analysis. E. Menghetti conceived, coordinated, and participated in the design of the study. All authors read and approved the final version of the manuscript.

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Clinical Study

The Association of Weight Status with Physical Fitness among Chinese Children

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Objective. To investigate the association of weight status with physical fitness among Chinese children. *Methods*. A total of 6929 children aged 6–12 years were selected from 15 primary schools of 5 provincial capital cities in eastern China. The height and fasting body weight were measured. The age-, sex-specific BMI WHO criteria was used to define underweight, overweight and obesity. Physical fitness parameters including standing broad jump, 50 m sprint, and 50 m*8 shuttle run were tested. *Results*. The prevalence of underweight, overweight, and obesity was 3.1%, 14.9%, and 7.8%, respectively. Boys performed better than girls, and the older children performed better than their younger counterparts for all physical fitness tests. No significant difference in all three physical fitness tests were found between children with underweight and with normal weight, and they both performed better than their counterparts with overweight and obese in all three physical fitness tests. The likelihood of achieving good performance was much lower among overweight and obese children in comparison with their counterparts with normal weight (OR = 0.13–0.54). *Conclusions*. An inverse association of obesity with cardiorespiratory fitness, muscle explosive strength, and speed was identified among Chinese children.

1. Introduction

The increasing prevalence of obesity is a major public health problem in both the developed and the developing world [1–3] In Asia, there is an alarming increase in the proportion of overweight and obese children and adolescents especially in countries undergoing nutritional and lifestyle transition, such as China [1, 4]. In 1982, the prevalence of overweight and obese youngsters in China was 1.2% and 0.2%, respectively. The rates increased in triple or more with 4.4% for overweight and 0.9% for obesity in 2002 [1].

Childhood obesity is a risk factor for a number of chronic diseases including heart disease, some cancers, and osteoarthritis in adulthood life. Some diseases, however, can become manifest during childhood, particularly type 2 diabetes [5]. In addition, some studies reported that overweight and obesity decreased the physical exercise capability and then reduced health-related physical fitness, such as cardiorespiratory fitness and speed of movement [6, 7]. Maintaining an appropriate level of health-related physical fitness allows a person to participate and enjoy physical activity, and reduce the risk of disease and injury. Report on the Physical Fitness and Health Surveillance of Chinese School Students in 2005, revealed that muscular explosive strength, cardiorespiratory fitness, and speed of movement in Chinese children has been decreasing during the past two decades [8]. With the rapid increase in obesity and decrease in physical fitness among Chinese children, we assume a relationship between overweight/obesity and health-related physical fitness in Chinese children. Some previous studies indicated the relationship between obesity and physical fitness performance in Caucasian children [9, 10]. However, ethnic differences in body composition are evident with a higher %BF, less FFM in Asians than Caucasians at the same BMI [11–14]. Limited study on this relationship was conducted in a large sample in Chinese children.

Moreover, underweight is still a public health problem in China which is undergoing nutritional and lifestyle transition. It is meaningful to explore the relationship between underweight and physical fitness performance, in addition to obesity. Few data are available in a large sample of Chinese children. Therefore, the purpose of the current paper is to explore the association of underweight, overweight, and obesity with physical fitness among Chinese children.

2. Subjects and Methods

Five provincial capital cities in eastern China, including Haerbin, Beijing, Shandong, Shanghai, and Guangzhou were selected for this study. Six primary schools were randomly selected from each selected city. Two classes from each grade from each selected school were randomly selected. All students in the selected classes were recruited as the study subjects.

This study was approved by the Ethical Review Committee of the National Institute for Nutrition and Food Safety and Chinese Center for Disease Control and Prevention. A written consent from parent and the oral consent from each subject were obtained.

2.1. Anthropometric Measurement. Height was measured to the nearest 0.1 cm in bare feet. Fasting body weight was measured to the nearest 0.1 kg using a balance-beam scale (RGT-140, Weighing Apparatus Co. Ltd. Changzhou Wujin, China) with participants wearing lightweight clothing. All the measurements were taken by trained investigators following standard operation procedure.

BMI was calculated by dividing weight by the square of height (BMI = weight (kg)/height (m)^2).

Underweight, overweight, and obesity was classified according to the WHO age- and sex-specific BMI cut-off points [15].

2.2. Physical Fitness Measurements. Three physical fitness tests were measured in our study, including standing broad jump, 50 m sprint, and 50 m*8 shuttle run. The standing broad jump was used to evaluate lower limb explosive strength. Participants stood with the feet immediately behind the starting line and separate from each other approximately with the shoulder's width over a nonslippery and hard surface. Participants jumped as longest as possible with two feet together. The longest jumping distance of triplicate attempts was recorded in centimeters. The 50 m sprint was measured to evaluate the speed of movement. Participants were instructed to run in a straight line and at the highest speed possible. The test was performed once and recorded to the nearest 0.1 s (CASIO, HS-70W stopwatch). The 50 m*8 shuttle run was measured to evaluate the cardiorespiratory fitness and agility. This test required participants to run back and forth 8 times along a track between two poles set 50 m apart at the highest speed possible and to turn round the poles counterclockwise. The test performed once and recorded to the nearest 0.1 s (CASIO, HS-70W stopwatch).

The physical education teachers showed the children how to do the tests in details. In order to encourage all participants to try their best in the physical fitness tests, they were informed that the test results would be recorded as the performance physical education for the semester. All the measures were taken by trained physical education teachers.

2.3. Statistical Analysis. Chi-square test was used to compare the age and sex difference in the prevalence of underweight, overweight, and obesity. Continuous variables were described as mean ± standard deviation (SD). T-test and one-way analysis of variance (ANOVA) were used to compare the age and gender differences in physical fitness test results. Weight status differences in physical fitness test results were compared using analysis of covariance (ANCOVA) with Bonferroni multiple comparison after controlling age and sex. Odds ratio (OR) was calculated by Cochran-Mantel-Haenszel Statistics to explore the likelihood of good performance (more than age- and gender-specific 75th percentile and 90th percentiles of each physical fitness test result, respectively [16]) in physical fitness tests in underweight, overweight and obese children compared with normal weight children adjusted for age and gender. It was considered significant if P value < .05.

3. Results

A total of 6929 elementary children (3604 boys, 3325 girls) aged 6–11 years (9.2 ± 1.4 years) were enrolled into the study and completed the anthropometric measurements. A total of 6767 children completed the test of standing broad jump and 6649 children completed 50 m sprint, while 4771 children completed 50 m*8 shuttle run. As all participants in Beijing did not perform the test due to the restriction caused by the epidemic of swine flu during the data collection, high dropout rate in 50 m*8 shuttle run was obtained. No significant differences in age, sex, height, and weight were found between the dropout group and the study sample.

The overall prevalence of underweight, overweight, and obesity was 3.1%, 14.9% and 7.8%, respectively (Table 1). The proportions of overweight and obesity among boys were significantly higher than that among their female counterparts (16.2% versus 13.6%; 10.3% versus 5.1%, respectively). The prevalence of underweight among boys was lower than girls (2.0% versus 4.7%). No significant differences in prevalence of underweight, overweight, and obesity were found among age groups.

The physical fitness test results by age and gender were shown in Table 2. The distance of standing broad jump

Table 1: The prevalence of overweight and obesity in Chinese children aged 6–11 years by gender and age (%).

	Boys				Girls			
Age (years)	*N*	Underweight	Overweight	Obesity	*N*	Underweight	Overweight	Obesity
6	157	2.0	18.5	9.5	178	2.8	12.4	3.4
7	617	1.5	11.0	9.7	598	2.9	9.9	5.3
8	879	0.7	16.0	10.8	771	3.3	14.8	5.3
9	814	2.6	16.7	9.8	771	6.4	16.3	4.9
10	695	1.5	19.4	11.9	638	5.7	13.9	5.8
11	442	4.8	16.7	8.4	369	6.5	11.1	3.8
Total	3604	2.0	16.2	10.3	3325	4.7	13.6	5.1

Significant difference in the prevalence of underweight, overweight, and obesity using Chi-square test between boys and girls in all ages with $P < .001$.

Table 2: Physical fitness test results by age and gender (Mean ± SD).

Age	Standing broad jump(cm)		50 m sprint (s)		50 m*8 shuttle run (s)	
(years)	Boys	Girls	Boys	Girls	Boys	Girls
6	122.1 ± 15.7	112.6 ± 16.1	11.2 ± 1.1	11.8 ± 1.2	137.1 ± 15.2	138.9 ± 18.1
7	130.0 ± 17.8	122.4 ± 16.9	10.9 ± 1.2	11.2 ± 1.3	134.2 ± 18.9	135.3 ± 17.6
8	140.1 ± 18.3	130.7 ± 17.7	10.4 ± 1.2	10.8 ± 1.2	129.7 ± 18.4	132.3 ± 16.0
9	149.7 ± 19.8	140.6 ± 18.3	10.1 ± 1.3	10.4 ± 1.1	124.7 ± 18.4	128.7 ± 16.8
10	157.3 ± 20.6	149.2 ± 17.5	9.7 ± 1.3	10.1 ± 1.2	120.8 ± 16.6	123.6 ± 15.6
11	164.5 ± 21.9	156.0 ± 19.3	9.9 ± 1.6	10.1 ± 1.5	119.8 ± 19.0	120.8 ± 13.9
Total	146.1 ± 22.9	136.9 ± 21.6	10.3 ± 1.4	10.6 ± 1.3	127.2 ± 18.8	130.0 ± 17.2

Significant difference in all three physical fitness test results between boys and girls using *t*-test with $P < .001$.
Significant difference in all three physical fitness test results among age groups using ANOVA test with $P < .001$.

in boys was significantly longer than that in girls (146 cm versus 137 cm). Boys run significantly faster than girls in both 50 m sprint (10.3 s versus 10.6 s) and 50 m*8 shuttle run (127.2 s versus 130.0 s) across all age groups. Older children performed better in all three physical fitness tests than their younger counterparts within the same gender subgroup.

Table 3 shows the comparisons in physical fitness test results among children with underweight, normal weight, overweight and obesity. No significant differences in all three physical fitness test results were found among different weight status group after controlling for age and gender. No significant differences in all three physical fitness test results between underweight and normal-weight children were found. Both underweight and normal-weight children had higher value in distance of standing broad jump while lower time of 50 m sprint and 50 m*8 shuttle run than their overweight and obesity counterparts. The distance of standing broad jump increased along with the increase of BMI value till to the overweight cut-off points and then decreased along with BMI decrease ($P < .001$ for trend test) (Figure 1). The time of 50 m sprint and 50 m*8 shuttle run decreased along with the increase of BMI till to the overweight cut-offs and then increased with BMI ($P < .001$ for trend test) (Figures 2 and 3).

Table 4 indicates the proportion of children with physical fitness tests results above the age- and gender-specific 75th percentile and 90th percentile by weight status. Less than 9% obese children had a result above the 75th percentile of each physical fitness test, and less than 4% obese children had a result above the 90th percentile of each physical fitness test

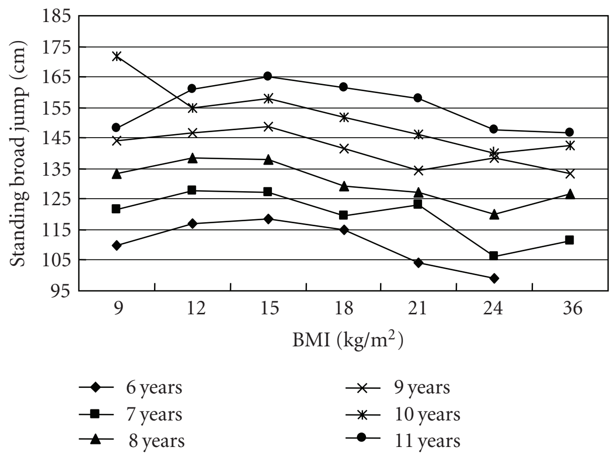

Figure 1: The association of standing broad jump length (cm) with BMI (kg/m^2) in 6775 Chinese children aged 6–11 years.

after adjusted for age and gender. The likelihood of failure to pass the physical fitness tests among overweight children was 2-3 times than their normal weight counterparts. The obese children had about 4, 7, and 8 time risk for no passing (less than 90th percentile) the standing broad jump, 50 m sprint, and 50 m*8 shuttle run, respectively, compared with normal-weight children. No significant increase risk for no passing these tests in underweight children was found compared with normal-weight children.

Table 3: Mean in physical fitness test results for underweight, normal weight, overweight, and obesity group by gender (Mean ± SD).

	Standing broad jump (cm)	50 m sprint (s)	50 m*8 shuttle run (s)
Boys			
Underweight	152.6 ± 23.5	10.2 ± 1.5	123.1 ± 16.5
Normal weight	149.0 ± 22.2	10.1 ± 1.3	123.5 ± 16.7
Overweight	140.6 ± 22.1	10.5 ± 1.4	131.8 ± 20.2
Obesity	132.0 ± 21.1	11.2 ± 1.4	142.1 ± 19.8
Girls			
Underweight	140.0 ± 19.4	10.6 ± 1.1	124.7 ± 15.3
Normal weight	138.1 ± 21.5	10.5 ± 1.3	128.4 ± 16.4
Overweight	132.2 ± 21.2	10.8 ± 1.3	134.6 ± 17.7
Obesity	128.8 ± 21.4	11.2 ± 1.5	141.5 ± 20.2

Significant difference in physical fitness test results among children with normal weight, overweight, and obesity using ANCOVA test with $P < .001$.

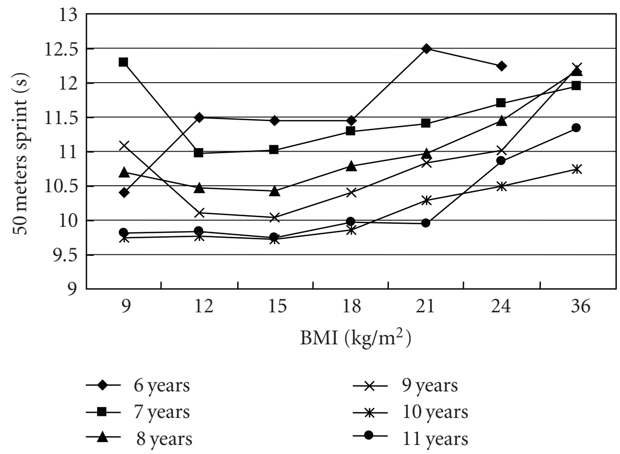

Figure 2: The association of 50 m sprint time (s) with BMI (kg/m^2) in 6775 Chinese children aged 6–11 years.

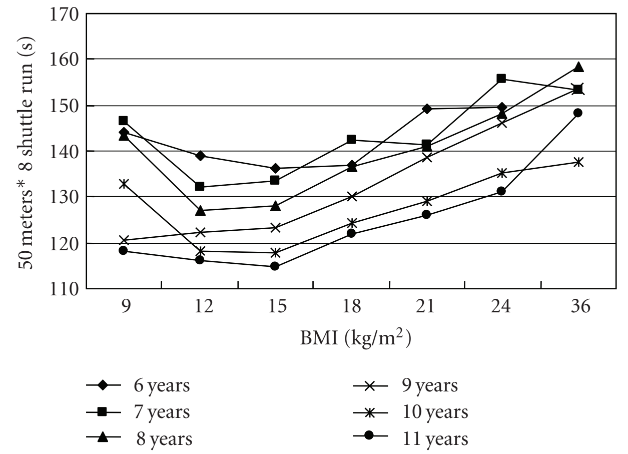

Figure 3: The association of 50 m*8 shuttle run time (s) with BMI (kg/m^2) in 4771 Chinese children aged 6–11 years.

4. Discussion

Our results revealed that the overweight and obese children performed worse in standing broad jump, 50 m sprint and 50 m*8 shuttle run compared with normal weight children. The results are agreement with previous studies. With the accumulation of body fat, explosive strength, cardiorespiratory fitness, speed, and agility of children declines continuously [16–21].

Maintaining an appropriate level of health-related physical fitness allows a person to participate and enjoy physical activity and reduce the risk of disease and injury [22, 23]. Health-related physical fitness includes the characteristics of functional capacity, such as muscular strength, cardiovascular endurance and motor ability [24]. In China, similar to other countries, the Physical Fitness and Health Surveillance of Chinese School Students includes the three components of fitness, such as standing broad jump, 50 m sprint, and 50 m*8 shuttle run. Therefore, we selected the three tests to evaluate the health-related fitness in the current study. All of the three tests required propulsion or lifting of body which was disadvantage in overweight and obese children due to the extra body load to be moved while performing these tests. However, overweight and obesity children can perform equally well or even better than children with normal weight in those muscular fitness tests where their body does not have to be transported, such as handgrip strength test [25]. Some studies also showed that obese children had similar cardiovascular fitness to normal-weight children after adjustment for body composition [26]. However, the obese children are inconvenient in mobility and less self-confidence, which makes them to participate in less physical activities and subsequently, the low physical activity level will increase risk for chronic disease.

No significant differences in physical fitness performance between underweight and normal-weight children were found in our study. However, some previous studies indicated underweight children and adolescents had poorer performance for sit-up and sit-and-reach [20], running endurance [27] and push-up [16] than their normal-weight counterparts. One of the main reasons for this inconsistency might be the low grade of the underweight. The difference in mean BMI of underweight and normal weight groups was only about 2 kg/m^2. Only urban children were involved into

Table 4: Proportion of children with test result above the age- and gender-specific 75th percentile (P75) and 90th percentile (P90) by body weight status.

	>P75			>P90		
	%	OR	95% CI	%	OR	95% CI
Standing broad jump						
Underweight	32.9	1.22	0.91–1.63	10.2	0.81	0.52–1.27
Normal weight	28.8	1.00	—	12.5	1.00	—
Overweight	14.2	0.41	0.34–0.49	4.6	0.34	0.25–0.46
Obesity	8.5	0.23	0.17–0.32	3.3	0.24	0.15–0.39
50 m sprint						
Underweight	27.4	0.85	0.62–1.15	11.4	0.88	0.57–1.35
Normal weight	30.8	1.00	—	12.7	1.00	—
Overweight	19.4	0.54	0.46–0.64	6.1	0.45	0.34–0.59
Obesity	8.9	0.22	0.16–0.30	2.1	0.15	0.08–0.28
50 m*8 shuttle run						
Underweight	36.1	1.36	0.96–1.91	15.0	1.21	0.77–1.91
Normal weight	29.3	1.00	—	12.9	1.00	—
Overweight	13.9	0.39	0.31–0.48	5.6	0.40	0.29–0.54
Obesity	7.1	0.31	0.23–0.42	2.0	0.13	0.07–0.27

our five study sites which are top developed area in China and the prevalence of underweight was low (3.1%).

Boys showed better performance than girls in all fitness tests at all ages, which was similar to the previous studies [28–30]. For example, Pangrazi and Corbin indicated that boys performed better than girls in explosive strength, endurance of muscles, and speed [31]. Consistent with previous studies, the present study also found older children performed better than their younger counterparts [32]. The age and gender differences in physical fitness performance can be explained, in part, by the age and gender difference in body composition. Boys have greater muscle mass, bone density, and less body fat than girl across age groups and older children have greater bone density and muscle mass than younger children [17, 33–35]. Moreover, compared with girls, boys were more physical active [36].

In addition, in the present study, we found the prevalence of overweight and obesity was 14.9% and 7.8%, respectively, in Chinese urban children in 2008, which is much higher than that in 2002 China National Nutrition and Health Survey (CNNHS). In 2002, the prevalence of overweight and obesity in Chinese urban children were 8.5% and 4.4%, respectively [37]. Despite the current sample was less representative than the 2002 CNNHS, the rapid increasing of overweight and obesity can still be evident.

There are some limitations of the current study. Firstly, only three physical fitness tests were measured which were not able to assess the overall physical fitness. Secondly, Weight status was classified on the basis of BMI in our study. However, BMI is an index of relative weight rather than body fat and it cannot differentiate the levels of fatness and leanness among individuals. Thirdly, given that sex maturation play important role on the physical fitness performance, we only collected the information on the age of menarche for girls and first nocturnal emission for boys but pubertal stage. However, the age of the study population ranged from 7 to 11 years and 97.4% girls and 99.92% boys were without menarche/nocturnal emission. The exclusion of these participants had no effect on the relationship between weight status and physical fitness (data not shown). In addition, our study is a cross-sectional study which cannot make the conclusion whether obesity causes low fitness or vice versa.

5. Conclusions

It is concluded that the overweight and obese children performed worse in cardiorespiratory fitness, muscle explosive strength, and speed compared with normal weight children.

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Clinical Study

Objectively Measured Physical Activity and Body Mass Index in Preschool Children

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Aim. To examine the association between objectively measured physical activity (PA) and body mass index (BMI) in preschool children. *Methods*. The study comprised 281 children (55.9% boys) aged from 4 to 6 years. PA was measured by accelerometer. Children were categorized as non-overweight (NOW) and overweight/obese (OW) according to the sex-adjusted BMI z-score (<1 and ≥ 1, resp.). *Results*. Total and moderate intensity PA were not associated with BMI. We observed that a higher proportion of OW children were classified as low-vigorous PA compared to their NOW peers (43.9 versus 32.1%, resp., $P > .05$). Logistic regression analysis showed that children with low-vigorous PA had higher odds ratio (OR) to be classified as OW compared to those with high-vigorous PA (OR = 4.4; 95% CI: 1.4–13.4; $P = .008$) after adjusting for BMI at first and second years of life and other potential confounders. *Conclusion*. The data suggests that vigorous PA may play a key role in the obesity development already at pre-school age.

1. Introduction

The prevalence of childhood obesity has been rising during the past decades in many parts of the world [1]. In Portugal, there is a high prevalence of overweight and obese children [2] and adolescents [3]. This picture is particularly alarming owing to the increasing risk of developing cardiovascular diseases in overweight and obese individuals [4, 5]. Over the long term, childhood/adolescence overweight is strongly associated with adult obesity [6, 7]. Therefore, it is of clinical and public health importance to examine the risk trends in order to develop effective preventive strategies targeting those at risk start as early as possible.

Human obesity is a multifactorial disorder where both genes [8] and lifestyle factors, including diet and physical activity [9] are important contributors. Both maternal and paternal body mass index (BMI) has also a strong influence on offspring's risk of obesity [10, 11]. Other determinants of childhood obesity include birth weight and weight gain that occur during the first years of life [12–14].

It has been suggested that obesity during the pre-school years is associated with other clinical factors easily assessed at birth [15]. For instance, it was found an association between birth weight and the risk of being obese in children at the age of 4, 8, 10, and 12 years [16].

Besides the previously mentioned factors, there exist other potentially modifiable factors that increase the risk of overweight in childhood and adolescence. These include: (i) intrauterine life: excessive gestational weight gain [17, 18], and maternal smoking during pregnancy [13, 19, 20]; (ii) infancy and pre-school period: reduced breastfeeding duration [21], excessive weight gain in the first 2 years of life [12, 22], excessive television [23–25], short sleep duration [12, 26, 27], and low levels of physical activity (PA) [28–30].

Studies examining the associations between PA and body fat in young children are scarce [12, 28, 30], and to the best of our knowledge, few studies have estimated the associations between objectively measured PA and BMI in preschoolers [28, 30]. Furthermore, there is no information available in Portuguese population.

The purpose of this study was to analyze the association between objectively measured PA and BMI in Portuguese preschoolers.

2. Methods

2.1. Participants and Data Collection. This is a cross-sectional study carried out in Portuguese (metropolitan area of Porto) kindergartens enrolled in the Preschool Physical Activity, Body Composition and Lifestyle Study (PRESTYLE). A total of 281 healthy pre-school children (55.9% boys) aged 4–6 years with complete information on the variables of interest were included in the study. Data collection took place between April 2009 and November 2009.

Informed written consent was obtained from parents and school supervisors. Study procedures were approved by the Portuguese Foundation for Science and Technology and by the Scientific Board of Physical Activity and Health PhD program.

2.2. Anthropometric Measures. Body weight and height were measured by standard anthropometric methods. Body weight was measured to the nearest 0.10 kg, with participants lightly dressed (underwear and tee-shirt) using a portable digital beam scale (Tanita Inner Scan BC 532). Body height was measured to the nearest millimetre in bare or stocking feet with children standing upright against a Holtain portable stadiometer (Tanita). The measurements were repeated twice and the average was recorded. BMI was calculated as body mass (kg) divided by height (m) squared. Children were classified as either non-overweight (NOW) or overweight (OW) according to the sex-adjusted BMI z-score (<1 SD and ≥1 SD, respectively). Children were evaluated during school day by trained teachers.

2.3. Physical Activity. PA was measured using Actigraph accelerometers, model GTM1 (Pensacola, FL 32502. USA). This is a small, lightweight, uniaxial device. This accelerometer produces "raw" output in activity counts per minute (cpm), which gives information about the total amount of PA [31]. The accelerometer output can also be interpreted using specific cut points, which describes different PA intensities PA. Data reduction, cleaning, and analyses of accelerometer data were performed as described elsewhere [32, 33]. Data were analysed using specific paediatric cut points, which have been validated for young children: ≥1100 and ≤1680 cpm for low PA [34], >1680 cpm for moderate PA, and >3360 cpm for vigorous PA (VPA) [35]. In this study, the epoch duration was set to 5 seconds, which seems to be more accurate and suitable concerning the spontaneous and intermittent activities of the young children [36].

A minimum of 10 hours per day was considered as valid data for the analysis. Parents were instructed to place the accelerometer on the child right after waking up and remove it before going to sleep. The accelerometer was adjusted at the child's right hip by an elastic waist belt under clothing (own cloth and school coat). A data sheet was given to the children's teachers, who were instructed to record the time when the child arrived and left the school. Activities were not prescribed or directed by the teachers or researchers. All children participated in normal activities with their classmates.

All PA intensity levels were defined by sex- and age-specific tertiles. Children belonging to the first, second, and third tertiles were defined as low, middle and high PA levels, respectively.

2.4. Potential Confounders

2.4.1. Pre- and Postnatal and Lifestyle Factors. Mothers reported information regarding gestational weight gain, maternal smoking during pregnancy, birth weight as well as body weight and height during their offspring's first and second year of life. Gestational weight gain was categorized according to Institute of Medicine [37] as below, optimal, and above gestational weight gain, while maternal smoking during pregnancy was categorized as YES or NO.

Mothers also reported the amount of screen time (watching television and/or playing videogames) the child spends daily as well as the sleeping time for both week days and weekends. Screen time questions were analyzed as continuous variables (converted to minutes) and also evaluated as a dichotomous variable based on young children recommendation [38]. Then, children were classified as those who accomplished guidelines (watching <2 hours/day) and those who did not (watching ≥2 hours/day).

2.4.2. Mother Information. Mothers reported their body weight and height, and we calculated BMI. Mothers were categorized as normal weight ($18.5\,kg/m^2 \geq$ BMI $<25\,kg/m^2$); overweight ($25\,kg/m^2 \geq$ BMI $<30\,kg/m^2$), and obese (BMI $\geq 30\,kg/m^2$) [39].

Socioeconomic status (SES) was defined as the mother's educational level and occupation [40]. The SES was defined based upon Portuguese Educational system a 9 years' education or less subsecondary level (scored as 1), 10–12 years' education, secondary level (scored as 2) and higher education (scored as 3). Levels 1, 2, and 3 were considered as low, middle, and high SES [41].

2.5. Statistical Analysis. Means and standard deviations were calculated to describe children's characteristics by weight status (i.e., NOW and OW).

Comparisons between weight status and PA patterns were conducted with *t*-test for continuous variables and chi-square test for categorical variables.

Following bivariates correlation analysis we conducted logistic regression to examine the association between weight status and all other variables (physical activity patterns, gestational weight gain, smoking during pregnancy, BMI first year of life, BMI second year of life, daily screen time, daily sleep time).

Table 1: Descriptive statistics of study participants.

	All Group $N = 281$	N-OW $N = 240$	OW $N = 41$	P
Age (years)	5.03 ± 0.81	5.01 ± 0.82	5.14 ± 0.72	.264
Weight (Kg)	21.11 ± 4.42	20.12 ± 3.14	27.92 ± 5.73	**<.001**
Height (m)	1.11 ± 0.08	1.10 ± 0.08	1.14 ± 0.08	**.005**
BMI (Kg /m^2)	17.03 ± 2.12	16.43 ± 1.29	21.11 ± 2.20	**<.001**
BMI z-score		−0.28 ± 0.61	1.92 ± 1.04	**<.001**
TPA (minutes)	134 ± 35	134 ± 36	133 ± 29	.863
MPA (minutes)	58 ± 14	58 ± 14	58 ± 13	.882
VPA (minutes)	38 ± 14	38 ± 14	35 ± 12	.293
Physical Activity Patterns (%)				
TPA				
Low Activity	32.4	33.3	26.8	
Middle Activity	34.9	32.9	46.3	.249
High Activity	32.7	33.8	26.8	
MPA				
Low MPA	32.4	33.3	26.8	
Middle MPA	35.2	33.3	46.3	.273
High MPA	32.4	33.3	26.8	
VPA				
Low VIG	33.8	32.1	43.9	
Middle VIG	33.5	32.5	39.0	.064
High VIG	32.7	35.4	17.1	

TPA: Total Physical Activity; MPA: Moderate Physical Activity; VPA: Vigorous Physical Activity.

A stepwise logistic regression analysis was performed to examine the association between PA and weight status, adjusted for all variables independently associated with weight status.

Statistical analysis was performed using the SPSS 17.0 software (SPSS Inc., Chicago, IL, USA). The level of significance was set at $P \leq .05$.

3. Results

Table 1 shows descriptive statistics of preschoolers and parents by overweight status. The prevalence of overweight was 14.6%. Overweight (OW) children were heavier, taller, and had higher BMI than their NOW counterparts ($P \leq .05$). We observed no statistical significant differences between weight status categories in minutes of total, MPA and VPA. However, the data showed that a proportion of OW children (43.9%) were classified low VPA compared to NOW children (32.1%) ($P > .05$).

Logistic regression analysis showed that children with low vigorous PA had higher odds ratio (OR) to be classified as OW compared to those with high vigorous PA (OR = 4.4; 95% CI: 1.4–13.4; $P = .008$) after adjusting for BMI at first and second years of life and other potential confounders (Table 2).

4. Discussion

This study examined the association of different PA intensity levels with weight status of Portuguese preschoolers after adjusting for several potential confounding factors. This is an important and relevant topic since, to the best of our knowledge, little is known about how PA intensity is associated with obesity in pre-school children. Our data showed that differences in levels of VPA were associated with weight status in children as young as 4 to 6 years. This is worthy to notice because our data suggest that the VPA influenced the change in BMI from those earlier ages. Despite that, no statistical significant differences were found for levels of total and moderate PA.

Our findings concur with other studies showing that low levels of VPA were associated with body fatness during the adiposity rebound period [30]. Further, they also agree with studies in children and adolescents showing that only VPA (but not lower intensity levels) was associated with body fat [42]. Additionally, it was shown that within intervention groups, those who participated regularly and maintained the highest heart rates during PA sessions showed the greatest decreases in body fat and the greatest increases in bone density [43, 44]. On the other hand, adolescents who engaged in relatively large amounts of free-living vigorous PA were likely to be relatively fit and lean. [45]. These findings are worth commenting in terms of both PA interventions and public health policies.

The large standard deviations found in our study suggest a wide individual variations and highlight the importance of the participants' intraindividual variability in PA behaviour. Therefore, variation in PA levels may be particularly important in preschool children with regard to weight status. While there is a need to better understand the factors that

Table 2: Univariable and multivariable logistic regressions.

	Univariable Effects (odds ratio (95% CI))	*P* value	Multivariable Stepwise effects* (odds ratio (95% CI))	*P* value
TPA (Low TERTILE)	1.7 (0.8–3.9)	>.05		
TPA (Middle TERTILE)	1.0 (0.4–2.5)	>.05		
TPA (High TERTIL)—REF				
MPA (Low TERTILE)	1.7 (0.8–3.9)	>.05		
MPA (Middle TERTILE)	1.0 (0.4–2.4)	>.05		
MPA (High TERTIL)—REF				
VPA (Low TERTILE)	**2.8 (1.1–7.2)**	**.027**	**4.4(1.4–13.4)**	**.008**
VPA (Middle TERTILE)	2.5 (0.9–6.4)	>.05	2.9 (0.9–8.8)	>.05
VPA (High TERTILE)—REF				

TPA: Total Physical Activity; MPA: Moderate Physical Activity; VPA: Vigorous Physical Activity
*Adjusted for Birthweight. BMI 1 year. BMI 2 years. Gestacional Weight Gain. Maternal Smoking during pregnancy. Scream and Sleep Time and Mother BMI and Education.

influence PA in preschoolers and to learn how to help them to become more active, our study shows that PA promotion and interventions should focus on the more intense PA activities. Children have a natural tendency towards movement, there is information suggesting a decline of discretionary time on children's daily life [29] and, thus, the time allocated to spontaneous PA, which, in turn, tend to be highly active [46] it is reduced and several sedentary behaviors such as TV viewing, video games, and other activities involving many hours standing took the lead on children's daily behaviour [12, 24]. Therefore, promotion of organized PA programmes such as physical education at schools and organized sports activities [29] that usually request more intense activities must be taken into account when PA promotion strategies are being developed.

Some limitations of this study should be recognized. First, the study included pre-school children from one metropolitan area, which made it difficult to generalize these findings. Secondly, it is not possible to inferr causal relationships between pre-school PA level and overweight status with such a cross-sectional study design. Nevertheless, this study focuses on the assessment of PA levels in a pre-school sample using an objective measure, which enhances the confidence of our findings owing to the fact that accelerometers provide more valid PA assessment in children [35].

5. Conclusion

Our data suggests that VPA may play a key role in the obesity development already at pre-school age.

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Clinical Study

A School-Based Exercise Intervention Program Increases Muscle Strength in Prepubertal Boys

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This prospective controlled intervention study over 12 months evaluated the effect of exercise on muscular function, physical ability, and body composition in pre-pubertal boys. Sixty-eight boys aged 6–8 years, involved in a general school-based exercise program of 40 min per school day (200 min/week), were compared with 46 age-matched boys who participated in the general Swedish physical education curriculum of mean 60 min/week. Baseline and annual changes of body composition were measured by dual energy X-ray absorptiometry (DXA), stature, and body mass by standard equipments, isokinetic peak torque (PT) of the knee extensors, and flexors at 60 and 180 deg/sec by computerized dynamometer (Biodex) and vertical jump height (VJH) by a computerized electronic mat. The annual gain in stature and body mass was similar between the groups whereas the increase in total body and regional lean mass ($P < .001$) and fat mass ($P < .001$) was greater in the exercise group. The one-year gain in body mass-adjusted knee extensor and flexor PT at 180 deg/sec was significantly greater in the intervention group compared with the control group ($P < .01$, adjusted for age at baseline and $P < .001$, adjusted for age and muscle strength at baseline, resp.). There was no group difference in VJH. In conclusion, the increase in school-based physical education from 60 to 200 minutes per week enhances the development of lean body mass and muscle strength in pre-pubertal boys.

1. Introduction

Physical activity has been regarded as one of the most important life style factors that could improve a variety of health-related aspects, including musculoskeletal health. But studies have indicated that children and adults in the recent decades have become less physically active [1], and there is a growing concern that the more sedentary lifestyle might lead to increased obesity and increased risk factors for a variety of chronic diseases and fractures. In fact, some authors even infer that we should change our focus from improving bone mass to improving neuromuscular function through increased physical activity when trying to reduce the incidence of fractures, this through a reduction in the fall frequency [2].

Physical activity includes a variety of activities as it is defined as any bodily movement produced by skeletal muscles that result in energy expenditure [3]. Physical activity can thus be seen as a summary of different behaviour, including subcategories such as exercise, sport, leisure activities, dance, and transportation [4]. Exercise or training however is defined as a subset of physical activity that is planned, structured with repetitive bodily movement done as to improve or maintain one or more components of physical fitness [3]. Currently it is recommended that all growing children daily should participate in at least 60 cumulative minutes of moderate to vigorous physical activity that is developmentally appropriate, enjoyable, and includes a variety of activities [5], and at least 3 days per week should include activities of vigorous intensity [6]. In addition, recent recommendations add that specific bone and muscle strengthening activities each day ought to be included as to improve health [6].

In children and adolescents, it is well established that gains in strength and power are possible following prospective controlled short-term progressive resistance training programs two to three times per week. Reports show that muscle strength, muscle mass, and physical performance improved in both boys and girls [7–9]. There are also other health-related benefits that are associated with strength training, such as improved self-satisfaction, self-esteem, and body image [10]. Muscle mass, muscle strength and endurance are also significantly higher in young athletes than in sedentary controls [11–14] while the proportion of body fat usually is reported lower in athletes than in controls [14, 15].

To our knowledge there is not an extant literature on general exercise training of longer duration and its effect on neuromuscular development in young children. However, reports show positive effects on fat mass, physical fitness, and performance. A school-based program with expanded physical education lessons (4 lessons/week) during three years was effective in increasing children's physical performance and preventing excessive weight gain [16]. Similarly Ara et al. report that regular participation in at least 3 hours per week of sports activities as well as the compulsory physical education program for one year is associated with increased physical fitness, vertical jump height and lower body fat mass in Prepubertal boys [17]. After follow-up three years later, the physically active boys had increased their total lean mass to a greater extent and maintained their physical fitness during growth compared with controls [18]. Furthermore, during one year of regular sport-specific training young athlete boys increased their physical performance compared with untrained youth [19].

These studies provide important information about the musculoskeletal effects of resistance training programs in volunteers or of exercise training programs of longer duration but with obesity or physical fitness as main outcome. However, it still remains unclear whether a long-term, general, and moderately intense exercise program on population level could improve muscle mass and performance in children 6–8 years old. We have previously reported that this goal could be reached in Prepubertal girls [20] but there has been less evaluation of whether the same could be achieved in boys who are already more physically active during their spare time before the exercise intervention [21].

A population-based general exercise intervention program of moderate intensity was created by increasing the frequency of compulsory school physical education, and not the intensity, as to be able to include all children in the intervention, not only those who could stand a more high intense training. This study was designed to evaluate whether this intervention program could improve body composition, lower extremity muscle strength, and physical performance in Prepubertal boys. We hypothesized that the 12-month program would confer these benefits.

2. Materials and Methods

The Malmö Pediatric Osteoporosis Prevention (POP) Study, is a prospective controlled exercise intervention study designed to annually assess skeletal and muscle development in children from school start onwards [21, 22]. Baseline measurements in the intervention group were performed in August and September, just after school started and before the intervention was initiated. The follow-up evaluations were done in the same months one year later. The controls were evaluated in November and December with all follow-up measurements done during the same months but two years later. Annual changes (per 365 days) were then calculated for all measured parameters. The design was accepted as the literature suggests that bone mass, muscle mass, and muscle strength increase in a linear fashion during the Prepubertal period [21, 23–25], a design approved in previous publications [20–22, 26]. During the summer period, all children had a break for nine weeks when no additional exercise training was provided.

The study design has previously been reported in detail when reporting changes in bone mass [21], but in summary, all boys in grades 1 and 2 in one school in Malmö, Sweden were chosen as intervention group. Of the 89 boys, 84 agreed to participate (94% inclusion). Two boys were excluded as they were on medications known to affect bone metabolism, and at follow-up one boy declined participation, leaving 81 boys with measurements both at baseline and at follow-up. After statistical descriptive analysis, 7 boys were excluded for having extreme values, defined as >3 standard deviations (SD) above or below the mean, and 6 boys due to technical measurement errors, leaving 68 boys with a mean ± SD age of 7.8 ± 0.5 years (range 6.7–8.6) at baseline to be included in this report. The controls were volunteers from three neighboring schools in areas with a socioeconomic background similar to that of the intervention group. Sixty-eight boys agreed to participate at baseline. At follow-up, 9 had moved out of the region or declined further participation, and 1 was excluded due to medication known to affect bone metabolism. After statistical descriptive analysis, 7 boys were excluded for having extreme values and 5 due to technical measurement errors, leaving 46 controls with a mean ± SD age of 7.9 ± 0.6 years (range 6.7–8.9) at baseline to be included in this report. All participants were healthy and all Caucasians, except one boy adopted from Colombia.

In order to ascertain whether there was any selection bias at baseline, we have previously reported that there were no significant differences in the grade 1 examination regarding stature, body mass, and BMI of the boys, when a drop-out analysis compared the study participants and the nonparticipants [27]. Furthermore, there were no differences in baseline age, stature, body mass, BMI, total body or regional body composition, muscle strength, or vertical jump height between the boys that completed the study and those who were measured only at baseline (data not shown).

The intervention program included the general exercise program used within the Swedish school physical education curriculum, supervised by the regular physical educational teachers but with the training increased to 40 minutes per day, corresponding to 200 minutes per week, but no specific registration was done as regard participation rate. Before the study the intervention school had had the same duration of physical education as the control schools. The duration was chosen in order to maximize a range of health-related benefits beyond just the gain in bone mass, which has been shown to respond to shorter bouts of body mass-bearing exercise [28–31]. Also, the physical education classes did not consist of any programs specifically designed to enhance muscle and bone mass. Instead, the classes included ordinary school physical education, both indoor and outdoor general physical activities such as a variety of ball games (e.g. basketball, handball, and soccer), running, jumping, and climbing activities (e.g. tag, rope climbing, and gymnastics-related activities on various apparatus). These activities were increased in duration so as not to bore the children with repeated standardized activities and to minimize the drop-out frequency frequently reported to occur with other study designs [32] and with the aim that any ordinary teacher in any school in the future could initiate such a program. The intensity level of the intervention program was moderate although it varied from low to high depending on if the current activity was more play-like or more of a competing situation. The aim of the intervention in a longer perspective was to increase general physical activity and not just exercise or training. In the control schools, the same type of activities were used, but as a compulsory Swedish school curriculum consisting of a mean 60 minutes per week given in one or two sessions per week.

A questionnaire, previously used in several pediatric studies but slightly modified for the POP study [21, 22, 33], was answered by the children together with the parents at baseline and follow-up. The questionnaire evaluated lifestyle factors such as socioeconomic and ethnic background, diseases, medications, fractures, consumption of dairy products, exclusion of anything in the diet, and physical activity in school and during leisure time (organized physical activity outside of school). Organized exercise outside of school was calculated as the weekly time (hours) spent in organized exercise (hours/week).

Body mass was measured with an Avery Berkel HL120 electric scale and stature by a wall-tapered Holtain Stadiometer with the children dressed in light clothes without shoes. Body mass index (BMI) was calculated as body mass/stature^2 (kg/m^2). A research nurse assessed the Tanner [34] staging. All were classified in Tanner stage 1 both at baseline and at follow-up.

Total body, arms, and legs lean tissue mass (kg) and fat mass (kg) were measured by dual-energy X-ray absorptiometry (DXA, DPX-L version 1.3 z, Lunar, Madison, WI) in a total body scan. All scans were performed by two research technicians who also analyzed the scans. The precision, evaluated by duplicate measurements in 13 healthy children aged 7–15 years (mean age 10 years), was 3.7% for total body fat mass and 1.5% for total body lean tissue mass.

Isokinetic peak torque of the right knee extensors and flexors were evaluated by a computerized dynamometer (Biodex System 3). Two physiotherapists performed the measurements. During the testing, the participants were seated with their hips flexed to 85° from the anatomical position. The axis of the knee was aligned with the Biodex axis of rotation. The participants were secured in the chair according to the standard Biodex procedure using shin, thigh, pelvic, and upper crossing torso stabilization straps. When required, a 10 cm thick pad was used to fill the space between the participant's back and the support of the chair. When the lever arm of the Biodex was longer than the lower leg of the participant a small pad was used to adjust for the difference. All participants were instructed to place their arms across their chest during the testing. The knee was positioned at 90° of flexion and went through a 75° range of motion, stopping at 15° of flexion. Concentric isokinetic knee extension and flexion peak torque were tested at an angular velocity of 60 and 180°/sec. Three submaximal trials were given prior to each testing velocities to assist with familiarization to the testing. In the literature, a familiarization to procedure prior to test is recommended although its validity has not been confirmed [35]. A total of five maximal repetitions (flexion and extension) at 60° sec were performed. After 30–60 seconds rest, 10 maximal repetitions at 180°/sec for both flexion and extension were done, with the highest peak torque (Nm) recorded for all measurements. All subjects received both visual and verbal encouragement during testing to ensure maximum effort at each velocity and repetition. Simple instructions were given to help the subjects understand the task. These instructions were given to each child when placed on the machine and included: "I want you to push and pull as hard and fast as you can 5/10 times. I will cheer you on and you can watch the screen to see how hard you are pushing." Peak torque (Nm) at both 60° and 180°/sec for extension (PT_{Ex60}; PT_{Ex180}) and flexion (PT_{Fl60}; PT_{Fl180}) were normalized to body mass (kg) and expressed as Nm/kg. The torque data was corrected for gravity. A hard cushion setting of 1 was used and the data was not windowed. The intraindividual test variability, evaluated as the coefficient of variation for repeated measurements in 21 children, was 6.6% for PT_{Ex60}, 12.1% for PT_{Fl60}, 12.3% for PT_{Ex180}, and 9.1% for PT_{Fl180}.

Vertical jump height (VJH), an estimation of neuromuscular performance, was used to assess physical performance. The vertical jump test was performed on an electronic mat connected to a digital timer that registered the total time in the air (Product name "Time It"; Eleiko Sport, Halmstad, Sweden). From this data, the height of the jump in centimeters was automatically calculated from the computer included in the standard equipment. All vertical jumps were performed from a standing position, and participants were first required to jump onto the mat with both feet and then make a maximal vertical jump. Each subject performed three vertical jumps from which the highest jump (cm) was recorded. The intraindividual test variability, evaluated as the coefficient of variation for repeated measurements in 21 children, was 5.9%.

Informed written consent was obtained from parents or guardians prior to participation. The study was approved by the Ethics Committee of Lund University. Data are presented as mean with standard deviation (SD) or 95% confidence interval (95% CI). All prospective data were converted into annual changes according to the following formula: [(follow-up data − baseline data)/the duration of follow-up] and expressed as the absolute or percentage change from baseline. Analyses of covariance (ANCOVA) were then used to compare the trait-specific annual changes in the groups, and baseline age and baseline peak torque values were included as covariates if there was a significant difference between the groups at baseline. Life style factors prior to and after study start were analysed with Fisher's exact test and Student *t*-test, respectively. Total mean duration of exercise during the study was defined as (school physical education and organized exercise outside of school) at baseline and at follow-up divided by two. Pearson's correlation coefficient was used to examine the relationship between the annual changes in muscle strength with the total mean duration of exercise.

The study design would detect a minimal difference of 0.123 Nm/kg in the annual change in muscle strength (PT_{Ex60}) with 80% power and an alpha level of 0.05. The reason we chose PT_{Ex60} as our primary muscle force outcome is that there is evidence in the literature for a greater absolute increase in knee extensor compared to flexor muscle strength from age 9 to 21 years [36]. Training in children has also been reported to confer greater increase in knee extensor than in flexor peak torque [37].

3. Results

There were no differences at baseline in anthropometrics or body composition between the intervention and control group, with BMI reaching a borderline significant higher value in the intervention group ($P = .05$) (Table 1). Furthermore, there were no significant group differences at baseline in registered lifestyle factors. Before the intervention was initiated, there were no differences in total duration of physical activity, but when the intervention was initiated, the total duration of physical activity became greater in the intervention group than in the control group. At baseline, PT_{Fl60} and PT_{Fl180} (body mass-adjusted both $P < .001$) were both higher in the control group (Table 1).

The annual gain in stature and body mass during the 12-month follow-up period was similar in the two groups whereas there was a greater increase in regional lean tissue mass and total body and regional fat mass in the intervention group (Table 1). After adjustment for baseline age and baseline peak torque values, if there was a significant difference at baseline between the groups, the annual changes in knee extension and flexion peak torque (PT_{Ex180} and PT_{Fl180}) were significantly greater in the intervention than in the control group (Table 1). When peak torque was normalized to body mass, the gains in extension and flexor PT at 180 deg/sec were significantly greater in the intervention group compared with the control group ($P < .01$, adjusted for age at baseline and $P < .001$, adjusted for age and muscle strength at baseline, resp.) (Figure 2). Similar results were found when muscle strength was expressed relative to lean mass (data not shown). The total mean duration of exercise during the study period correlated with the annual gains in both PT_{Ex180} ($r = 0.19$, $P < .05$) and PT_{Fl180} ($r = 0.38$, $P < .001$) (Figure 1).

4. Discussion

This 12-month prospective, controlled, school-based exercise intervention study indicates that an increase in the duration of general moderately intense physical education in the school from 60 to 200 minutes per week is associated with an increased lower limb peak muscle strength gain in Prepubertal boys. A statistically significant difference between the groups can not automatically be transferred to a difference of biological and clinical significance; however, these findings still may have important public health implications as they provide evidence-based data to support the benefit of school-based physical education as an effective strategy to enhance muscular health in Prepubertal boys.

There are several reasons why it is beneficial to enhance musculoskeletal health during growth. Bone density, muscle mass, and muscle strength are all traits that play an important role in reducing the risk of a number of chronic musculoskeletal diseases in adulthood [38, 39] and these traits are positively affected by physical activity [11–14, 21, 22, 28–31, 40]. In this study, we report that it is enough to increase moderate intense exercise when trying to improve muscle strength in young boys. These findings are consistent with the findings in girls in similar ages [20]. They also support other reports which conclude that 10 months of school-based exercise intervention in girls aged 9-10 years for 30 minutes 3 times per week is associated with 7 to 33% greater shoulder and knee extension isokinetic peak torque and grip strength, when the intervention group is compared with the control group [14]. To our knowledge no other studies have reported the effect of school-based intervention programs on muscle strength in prepubertal boys. However, extracurricular sports participation of 3 hours/week is positively associated with leg muscle force measured on a force plate [17], and with a handheld dynamometer [41]. Others report no correlation between physical activity and leg muscle strength in prepubertal boys [42, 43].

Several effects may explain the benefits seen in muscle strength from increased physical activity. Training may confer neuromuscular adaptations in conjunction with increases in muscle mass and muscle size, which all increase during puberty in association with the increased secretion of sex steroids [37, 44]. But the gain in muscle strength in response to training in Prepubertal children may also primarily be the result of neural adaptations as muscle strength could significantly increase without a concomitant augmentation in muscle size, even after a period and intensity of training for which muscle hypertrophy is evident in adults [8, 9, 44]. In our study, the increases in muscle strength were independent of the changes in lean tissue mass, suggesting that other factors than the mass of the muscle contribute to the increase in the force-producing capacity of muscles. It has been suggested that gain in muscle strength in response to resistance training during growth is the result of changes in neural factors, including enhanced motor unit activation, coordination, recruitment, and/or firing frequency [7, 8, 44, 45]. However, whether the increase in muscle strength in children after a moderate intensity exercise program also can be accounted for by these neural adaptations is still unclear. Furthermore, changes in limb length and subsequently the muscle moment arm are also factors contributing to improvements in torque production as isokinetic peak torque and limb length are closely related [36, 46].

Table 1: Baseline data, annual unadjusted absolute changes, and adjusted difference in anthropometry, body composition, muscle strength, and vertical jump height in the intervention and control group.

	Baseline			Annual Changes			
	Intervention (n = 68)	Controls (n = 46)	P-value	Intervention (n = 68)	Controls (n = 46)	Adjusted difference (95% CI)	P-value
Age (years)	7.8 ± 0.5	7.9 ± 0.6	.23	—	—	—	
Anthropometry							
Stature (cm)	129.4 ± 6.3	129.5 ± 6.7	.48	5.6 (5.4, 5.9)	5.7 (5.5, 5.9)	−0.07 (−0.41, 0.27)	.70
Body mass (kg)	27.8 ± 4.7	26.8 ± 4.6	.08	3.0 (2.7, 3.3)	3.1 (2.8, 3.4)	−0.06 (−0.49, 0.37)	.79
BMI (kg/m^2)	16.5 ± 1.8	15.9 ± 1.7	.05	0.3 (0.2, 0.5)	0.3 (0.2, 0.5)	−0.03 (−0.24, 0.19)	.81
Total body fat (%)	13.2 ± 6.8	12.6 ± 5.4	.52	2.1 (1.5, 2.7)	1.3 (0.8, 1.7)	0.96 (0.15, 1.76)	**.02**
Lean body mass (kg)							
Total body	21.70 ± 2.74	21.50 ± 2.90	.24	2.28 (2.13, 2.43)	2.13 (2.00, 2.25)	0.15 (−0.06, 0.35)	.17
Legs	6.78 ± 1.15	6.68 ± 1.23	.16	1.00 (0.93, 1.06)	0.96 (0.90, 1.02)	0.03 (−0.06, 0.13)	.46
Arms	1.80 ± 0.35	1.81 ± 0.38	.65	0.30 (0.26, 0.34)	0.19 (0.17, 0.22)	0.11 (0.06, 0.16)	**<.001**
Fat mass (kg)							
Total body	3.56 ± 2.59	3.31 ± 2.01	.44	1.14 (0.88, 1.39)	0.81 (0.59, 1.03)	0.37 (0.01, 0.72)	**.04**
Legs	1.61 ± 0.96	1.46 ± 0.75	.26	0.43 (0.33, 0.53)	0.36 (0.27, 0.45)	0.08 (−0.06, 0.23)	.26
Arms	0.30 ± 0.31	0.34 ± 0.31	.61	0.14 (0.09, 0.18)	0.02 (−0.02, 0.04)	0.12 (0.07, 0.18)	**<.001**
Peak Torque—unadjusted (Nm)							
PT_{Ex60}	43.0 ± 9.9	43.4 ± 10.7	.56	10.2 (8.3, 12.1)	9.8 (8.3, 11.2)	0.74 (−1.79, 3.27)	.56
PT_{Fl60}	21.4 ± 6.4	24.4 ± 6.7	**.04**	8.6 (7.4, 9.9)	7.0 (6.0, 8.1)	1.66 (−0.15, 3.48)	.07
PT_{Ex180}	35.1 ± 7.7	35.4 ± 7.7	.47	8.7 (7.5, 9.9)	7.0 (6.2, 7.9)	1.77 (0.20, 3.35)	**.03**
PT_{Fl180}	19.0 ± 4.9	22.6 ± 5.2	**<.001**	9.7 (8.3, 11.1)	5.0 (4.3, 5.8)	4.87 (2.94, 6.80)	**<.001**
Peak Torque—body mass-adjusted (Nm/kg)							
PT_{Ex60}	1.54 ± 0.22	1.61 ± 0.27	.26	0.17 (0.11, 0.23)	0.14 (0.10, 0.18)	0.04 (−0.04, 0.12)	.37
PT_{Fl60}	0.77 ± 0.18	0.91 ± 0.20	**<.001**	0.21 (0.17, 0.25)	0.13 (0.09, 0.16)	0.04 (−0.01, 0.10)	.14
PT_{Ex180}	1.26 ± 0.17	1.32 ± 0.19	.25	0.16 (0.12, 0.19)	0.09 (0.07, 0.11)	0.07 (0.02, 0.12)	**.003**
PT_{Fl180}	0.69 ± 0.15	0.84 ± 0.11	**<.001**	0.25 (0.20, 0.29)	0.07 (0.05, 0.10)	0.14 (0.08, 0.21)	**<.001**
Physical performance							
Vertical jump height (cm)	24.2 ± 4.7	24.8 ± 4.3	.90	2.1 (1.0, 3.2)	1.3 (0.7, 1.9)	0.56 (−0.86, 1.97)	.44

The baseline values are presented as unadjusted means ± SD and the annual changes as unadjusted means with 95% confidence interval (95% CI). All baseline comparisons are adjusted for age at baseline. The differences between the annual changes in the intervention and the control group are presented adjusted for differences in age at baseline and, if there was a significant group difference at baseline, the baseline values for that specific measurement (accounts for PT_{EX60}, PT_{EX180}, PT_{Fl60} and PT_{Fl180}).

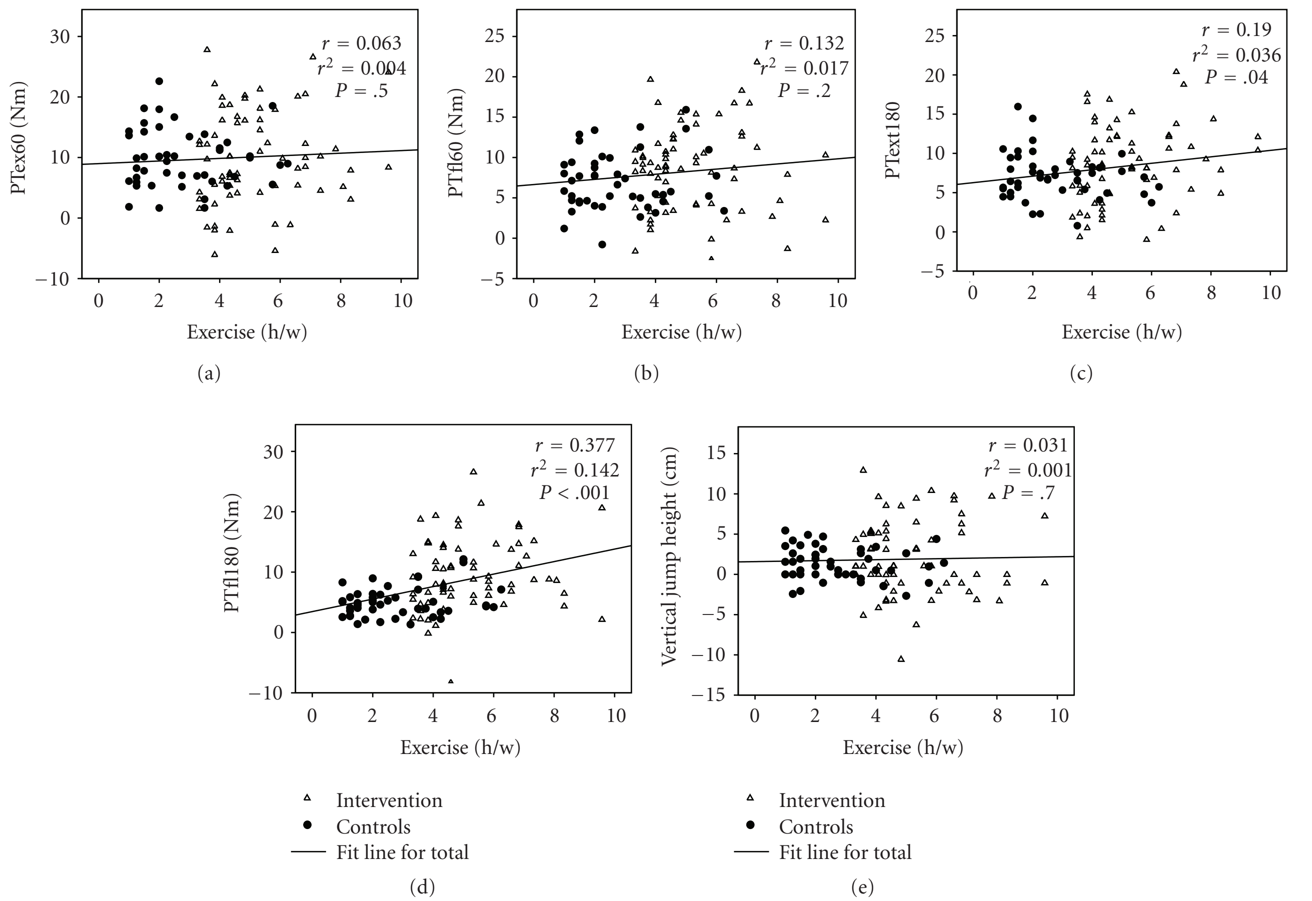

Figure 1: Correlation between total mean duration of exercise during the study and annual absolute gain in muscle strength (PT) and vertical jump height for interventions and controls.

Published studies that examined the effect of resistance training on muscle hypertrophy in children are usually short studies over weeks or months and studies that usually rely on limb circumference when estimating muscle mass or muscle size [7–9, 37]. The DXA technique, however, allows us to measure the mass of the lean tissue, which has shown to be comparable to *in vivo* techniques of measuring muscle mass [47, 48]. We observed that the 12-month school-based physical activity program was associated with a trend of gaining more lean mass in all regions, being significant only in the arms, relative to the control group (Table 1). These findings are consistent with the results of a 6-year prospective study reporting that boys in the upper quintile of habitual physical activity gain 3–6% more lean mass than those in the lowest quintile [11, 49]. Given that the boys in our study did not participate in a specific resistance training program, it seems that the exercise-induced gains in lean tissue mass were related to the relatively large increase in the duration of training (from 60 to 200 minutes per week) coupled with the follow-up period of 12 months. The finding of a correlation between total duration of physical activity and changes in muscle strength further supports the view that there really is a causal relationship between the duration of habitual physical activity and the gain in muscle strength in Prepubertal boys, even if it must be emphasised that the determination coefficient (r^2) indicates that the duration of physical activity during the study explained no more than 3.6%–14.4% of the variance in the reported traits (Figure 1).

Despite reports that general physical training can improve muscle strength in children, there are conflicting reports as to whether these benefits translate into improvements in other physical performance estimates such as athletic performance, VJH, long jump, or sprint speed [7, 9, 50, 51]. When we examined the exercise induced effects on VJH in this study, the gain in the exercise group was in absolute values an improvement relative to the control group although the difference was not statistically significant. This lack of statistical significance is consistent with previous reports, inferring that school-based exercise intervention is associated with a nonsignificant difference but a trend toward a greater improvement in the exercise compared to control girls for both VJH (~ 10%, $P = .14$) and long jump (~ 3%, $P = .10$) [29]. The lack of a significant difference in VJH in our study could be explained by the nonspecific nature of the training program and/or the inability of the test to accurately capture changes in functional performance. Since changes in VJH are believed to reflect neuromuscular adaptations [52], it could be that the activities provided in

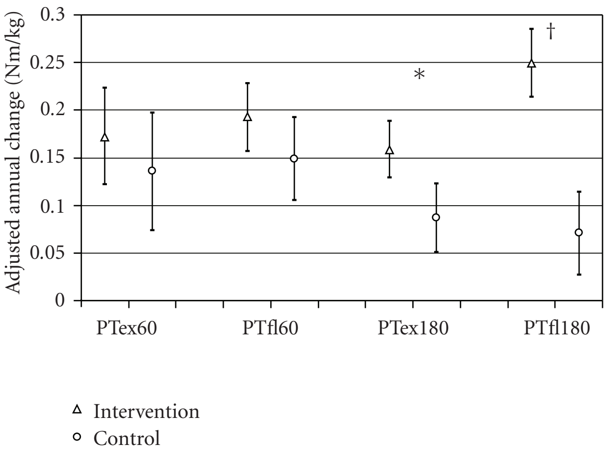

Figure 2: Mean, with 95% confidence interval, absolute annual changes in the body mass adjusted knee extension (ex), and flexion (fl) peak torque at 60 and 180°/sec in the intervention and control group. All data represent the annual changes adjusted for baseline age and the baseline values for that specific measurement, if there was a significant group difference at baseline. $^{*}P < .01$, $^{\dagger}P < .001$ versus control group.

our intervention did not specifically replicate the vertical jump movement pattern and thus were not sufficient to significantly improve jumping performance.

An unexpected finding in our study was the greater annual gain in arm fat mass in the intervention group compared with the controls (Table 1). However, others have also reported an increase in fat mass in children associated with increased physical training [20, 53]. The greater gain in fat mass in the intervention group in the present study could be explained by an increased food intake accompanying the increased training. Although we did not assess dietary habits, we have previously reported that the discrepancy in fat gain was most likely the result of other influences besides physical activity, because there was no dose-response relationship between the duration of exercise and gain in fat mass [21].

There are limitations to this study. This was not a randomized, controlled study, as randomization was refused by the principals, teachers, parents, and children since it was neither feasible nor practical for some children to be given additional exercise during compulsory school hours while others were not. But since all schools had a similar amount of regular school physical education before study start and since there were no differences in anthropometry between participants and nonparticipants or between participants and dropouts, the risk of selection bias seems minimal. Due to lack of resources in our research laboratory, the control group boys were not remeasured until after two years. However, as all the boys remained Prepubertal during the study, it was possible to compare the annual changes between the groups as the development of muscle strength is proportional to the gains in stature and body mass that occur linearly during this period [54, 55]. Third, the estimate of lean tissue mass and fat mass was made using DXA. Even though this technique is comparable to criterion *in vivo* techniques [47, 48], it has been shown that DXA-based body composition measures during growth can be influenced by differences in hydration status, body size, and fat distribution [56]. Another weakness is that we do not have measurements of leg length as changes in limb length could influence the muscle moment arm in relation to the improvement in torque production. Also, during the different breaks from school, there was no intervention given, a fact that if anything would reduce our estimated effect of the intervention program, due to possible detraining in the intervention group [50]. Finally, physical activity habits were assessed by questionnaire and limited to organized exercise only.

In conclusion, increasing the amount of moderately intense exercise within the school curriculum physical education to 40 minutes per day provides a feasible strategy to enhance muscle strength in Prepubertal boys. These findings have important clinical implications, as the first two decades in life may represent the most opportune time to reduce the risk of a number of chronic musculoskeletal health conditions [38]. Thus, the findings of this study support the notion that health benefits through increased school-based exercise for young boys can be achieved without adding external resources, costs, personnel, financial, or spatial resources to the school budget.

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Research Article

Genetic Influences on Individual Differences in Exercise Behavior during Adolescence

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The aim of this study was to investigate the degree to which genetic and environmental influences affect variation in adolescent exercise behavior. Data on regular leisure time exercise activities were analyzed in 8,355 adolescent twins, from three-age cohorts (13-14, 15-16, and 17–19 years). Exercise behavior was assessed with survey items about type of regular leisure time exercise, frequency, and duration of the activities. Participants were classified as sedentary, regular exercisers, or vigorous exercisers. The prevalence of moderate exercise behavior declined from age 13 to 19 years with a parallel increase in prevalence of sedentary behavior, whereas the prevalence of vigorous exercise behavior remained constant across age cohorts. Variation in exercise behavior was analyzed with genetic structural equation modeling employing a liability threshold model. Variation was largely accounted for by genetic factors (72% to 85% of the variance was explained by genetic factors), whereas shared environmental factors only accounted for a substantial part of the variation in girls aged 13-14 years (46%). We hypothesize that genetic effects on exercise ability may explain the high heritability of exercise behavior in this phase of life.

1. Introduction

Regular exercise has been cited to be a key contributor to health [1], whereas a sedentary lifestyle is proposed to be one of the main causes of the rise in obesity that starts at an increasingly younger age [2]. Despite the well-documented benefits of exercise, many people do not exercise on a regular basis [3]. As a consequence, a sedentary lifestyle, and the accompanying risk for obesity, remains a major threat to health in today's society. Studying exercise behavior during adolescence is of particular interest because several studies reported that the prevalence of exercise participation declines with increasing age, and that this decline is most prominent during adolescence [4–6].

To increase the success of intervention on this important health-related behavior, much research has been devoted to the determinants of exercise behavior. The main focus of these studies has been on social, demographic, and environmental characteristics, such as low socioeconomic status and low social support by family and peers [7–9]. None of these factors, however, have emerged as a strong causal determinant of exercise behavior, with the possible exception of gender, showing that exercise participation is higher in boys than it is in girls. Twin studies offer the possibility to assess the importance of genetic factors as determinants of exercise behavior. With data from twins, individual differences in behavior can be decomposed as due to genetic, shared environmental (environmental influences shared by members of the same family) and nonshared environmental influences (influences unique to an individual). The importance of genetic and environmental factors can be estimated by comparing the resemblance in exercise behavior between monozygotic (MZ) twins and dizygotic (DZ) twins. A greater resemblance of MZ twins, who are genetically identical, compared to DZ twins, who share on average half of their segregating genes, constitutes evidence for genetic influences on exercise behavior. If MZ twins resemble each other more than DZ twins, but not to the extent that would be expected based on their twice larger genetic resemblance, shared familial factors may also be important [10].

A number of twin studies have shown that genetic factors contribute to individual differences in exercise behavior and measures of exercise frequency, duration, and intensity during adolescence and adulthood [4, 11–15]. The genetic architecture of exercise behavior has been found to differ across the life span with the largest differences seen during adolescence [16]. In a Dutch twin study, Stubbe et al. [4] found that genetic variation was of no importance to leisure time exercise in 13- to 16-year-old adolescents. Instead, environmental influences shared by siblings from the same family accounted for the largest part of variation in exercise behavior. From age 17 the role of shared environmental influences rapidly waned and genetic influences started to dominate the individual variation in exercise behavior. A combination of genetic and shared environmental influences on exercise behavior in adolescence has also been reported by other studies [11, 12]. In contrast to Stubbe et al. [4] who found no difference in the genetic architecture between boys and girls, these studies suggested clear sex differences such that the shared environment lost its importance earlier in boys than in girls. In part, the discrepancies in the sex-specific genetic architecture across these previous studies may reflect insufficient statistical power to reliably detect age by sex effects.

In the present study, we examined the relative influence of genetic and environmental factors on self-reported leisure time exercise behavior in the largest sample of adolescent twins to date. Due to the large sample size this study was able to estimate genetic and environmental influences within three different age groups (13-14, 15-16, and 17–19 years) and to assess quantitative sex differences (e.g., differences in heritability) as well as qualitative sex differences (are the same genes expressed in boys and girls) in the genetic architecture within these age groups.

2. Methods

2.1. Subjects. Participants were registered with the Netherlands Twin Registry (NTR), established by the Department of Biological Psychology at the VU University in Amsterdam [17, 18]. The large majority of twins had been registered with the NTR as newborns. Parents of adolescent twins were asked for consent to send their children a survey. If their parents consented, twins and their nontwin siblings received an online or a paper and pencil self-report survey when they were 14, 16, and 18 years. The survey contained items about behavior, sport, lifestyle, and well-being. When twins and siblings did not return the survey on time they were contacted by mail for a first reminder and next they were contacted by phone for a second reminder. A total of 3,645 families with twins born between 1986 and 1994 participated in this ongoing study at least once so far. The overall family response rate is 56%.

Triplets and nontwin siblings were not included in the present paper. Furthermore, twins with an illness or handicap interfering with their daily lives were also not included. This resulted in a total sample of 8,355 twins (42% male) from complete and incomplete pairs, coming from 3,405 families. For 1,160 twins, data were available at two time points. Participants were primarily Caucasian and they came from all regions of The Netherlands (rural and urban areas). Data were available for 754 (17%) incomplete and 3,614 (83%) complete twin pairs. In Table 1, zygosity of the participating twin pairs is presented. For 1,089 (36.1%) of the same-sex twin pairs zygosity was determined based on blood group or DNA typing. Zygosity for the remaining same-sex twin pairs was determined by questionnaire items about physical similarities and confusion by family members and strangers. These items allow accurate determination of zygosity in 93% of same-sex twin pairs [19].

Table 1: Zygosity of participating twin pairs for the total sample and the different age groups (complete twin pairs added in parentheses).

	Total sample	13-14 yr	15-16 yr	17–19 yr
MZM	662 (585)	211 (197)	282 (249)	169 (139)
DZM	567 (465)	201 (170)	210 (184)	156 (111)
MZF	1042 (918)	343 (317)	380 (333)	319 (268)
DZF	738 (621)	231 (207)	265 (225)	242 (189)
DOS	1359 (1025)	516 (428)	494 (372)	349 (225)

Note. MZM: monozygotic male twin pair; DZM: dizygotic male twin pair; MZF: monozygotic female twin pair; DZF: dizygotic female twin pair; DOS: dizygotic opposite-sex twin pair.

Participants were divided into the age groups 13-14 years (33%), 15-16 years (38%), and 17–19 years (29%). Mean age in the three-age groups was 14.51 years (SD = 0.31), 16.23 (SD = 0.61), and 18.06 (SD = 0.70), respectively. The age groups were not completely independent, because for a small subset of participants data were available at two time points (e.g., twins returned a survey at age 14 and 16). Furthermore, since a small subset of participants participated in a pilot and short there after in the regular survey collection data from 2 surveys were present within one age group. For this subset of participants, data from the pilot version were excluded for the analyses. As can be seen in Table 1, each age group had adequate numbers of monozygotic (MZ) and dizygotic (DZ) twin pairs.

2.2. Exercise Behavior. Participants were asked to indicate what type(s) of regular leisure exercise they were involved in at the time of assessment. A list of 21 common individual (includes fitness centre, jogging, tennis, etc.) and team-based exercise activities (soccer, field hockey) was provided plus 5 open entries for less common activities. For each exercise activity endorsed, the participants further reported how many months per year, weekly frequency and the average duration of the activitiy. Ainsworth's Compendium of physical activity [20] was used to assign an MET score (Metabolic equivalent) to each exercise activity, reflecting its energy expenditure as a multiple of the basal energy expenditure (approximately 1 kcal/kg/hour) in an average subject engaged in that activity. When in high-school, Dutch adolescents have to attain physical education (PE) classes for 1–3 hours per week. The exact amount of MET hours weekly in these PE classes was assessed as a separate variable.

For each participant a total weekly MET score was computed across all exercise activities by summing the products of the number of hours spent weekly on each exercise activity and its MET score. Activities were only scored if that participants had engaged in them for at least three months during the past year. Exercise during physical education classes at school was not included in the weekly MET score. Thus the dependent variable reflects leisure time exercise behavior only.

Participants were classified into three groups based on their total MET scores. The first category consisted of sedentary participants whose total weekly MET score was lower than 5.0. The second category of moderate exercisers consisted of participants whose total weekly MET score ranged between 5.0 and 30.0. The third category consisted of vigorous exercisers whose total weekly MET score was 30.0 or higher.

2.3. Statistical Analyses. Because the data of exercise behavior were positively skewed, a liability threshold model was used to analyze individual differences in exercise behavior within each age group. The basic assumption underlying the liability threshold model, which was originally proposed by Falconer [21], is that an unobserved (latent) continuous liability underlies the skewed distribution of the observed variable (i.e., exercise behavior). The liability is assumed to be standard normal distributed (i.e., mean = 0, SD = 1). With family data, correlations between family members can be estimated for the liability, rather than for the observed trait. After obtaining the correlations between twins for the liability distribution, we employed genetic structural equation modeling to estimate the relative contributions of genetic and environmental influences to individual differences in liability to exercise behavior.

Participants were classified into three groups (i.e., sedentary, moderate exercise, vigorous exercise) as described above. In this way, ordinal scores on exercise behavior were obtained that were coded 0, 1, and 2. To model the three categories of exercise behavior two thresholds were required. The thresholds, expressed in z-values, are defined by the prevalence of the three categories of exercise behavior in the sample and represent the value in the latent liability distribution above which an individual will endorse the next category. In the lower part of Figure 1, the distribution of exercise liability is presented. As can be seen in the figure, the thresholds represented by the vertical lines, separate the exercise liability distribution into three distinct categories.

Resemblance in the liability to exercise behavior between twins is expressed in polychoric twin correlations. Comparing MZ twin correlations with DZ twin correlations provides a first step in evaluating the relative influence of genetic and environmental factors on individual differences in liability to exercise behavior. When the MZ correlation is higher than the DZ correlation, it is inferred that genetic variation influences individual differences in liability to exercise behavior. A DZ correlation higher than half the MZ correlation implies shared environmental effects, referring to environmental factors shared by all members of the same family, on liability to exercise behavior. Variation that is not due to genetic and shared environmental effects is attributed to environmental effects which are not shared by family members. The nonshared environmental variance component also includes measurement error variance. Comparing MZ and DZ twin correlations in boys and girls provides specific information regarding quantitative sex differences. When the difference between MZ and DZ twin correlations is larger in boys than in girls, it can be concluded that genetic influences are stronger in boys compared to girls. Specific information regarding qualitative sex differences can be derived from the DZ opposite-sex (DOS) correlation. When the twin correlation in DOS twin pairs is lower than predicted from the correlation in DZ-male and DZ-female twin pairs this might be due to genetic or shared environmental effects that influence one sex but not the other [21].

As a first step, the thresholds and polychoric twin correlations were estimated for each of the 5 sex by zygosity groups (i.e., MZM, DZM, MZF, DZF, and DOS) using the software package Mx [22]. Thresholds were estimated separately for boys and girls to take into account sex differences in the prevalence of exercise behavior. This model is referred to as a saturated model and simply specifies for each sex by zygosity group that the data from the first- and second-born twin are correlated without attempting to model these correlations as a function of genes or shared environment. Within a series of nested models we tested whether constraining the thresholds to be equal between boys and girls led to a significant deterioration of model fit. In addition, we tested whether twin correlations were significantly different for MZ and DZ twins.

Next, genetic models were fitted to the data in which the genetic architecture of liability to exercise behavior was specified for each age group. A graphical representation of the genetic model is given in Figure 1. The amount of variance in the underlying liability due to additive genetic (A), shared environmental (C), and nonshared environmental effects (E) can be estimated by considering the different level of genetic relatedness between MZ and DZ twin pairs. MZ twin pairs are genetically identical, whereas DZ twin pairs share on average 50% of their segregating genes. In the genetic models, the genetic correlation (rg) for MZ and DZ twin pairs is therefore fixed at 1.0 and 0.5 respectively. Shared environmental effects refer to environmental factors that are shared by all siblings in the family and therefore the shared environmental correlation (rc) is fixed at 1.0. In Figure 1, rg and rc are represented by the double-headed arrows connecting the latent genetic (A) and shared environmental factors (C) of both members of a twin pair. Nonshared environmental effects refer to environmental factors that are unique to individuals in the family and therefore these are uncorrelated between siblings. The influence of A, C, and E is represented by path coefficients a, c, and e (see Figure 1). Because it is assumed that the liability to exercise is standard normal distributed, the total variance under the liability distribution is 1. The influence of A, C, and E therefore also adds up to 1. Under this model, proportions of variance explained by genetic, shared environmental, and nonshared

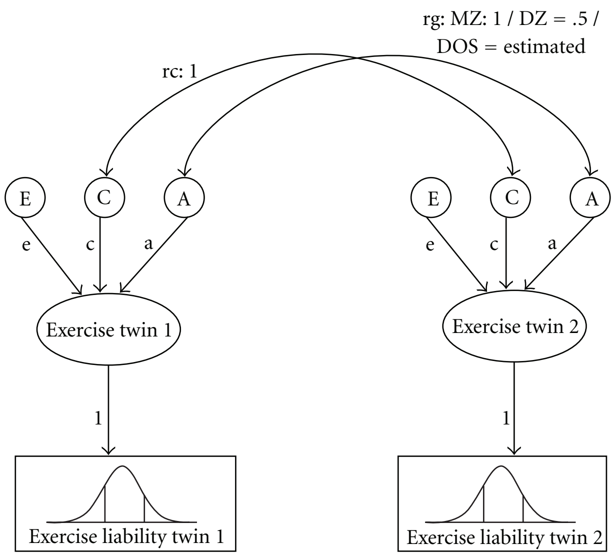

Figure 1: Univariate liability threshold model for twin data. Exercise behavior was measured with 3 categories (hence 2 thresholds are estimated). The total variance in liability is one and is modeled as caused by latent factors A (additive genetic influences), C (common or shared environment) and E (unique environment). The square of path coefficients a, c, and e gives the variance due to A, C and E.

environmental factors can be obtained by squaring the corresponding path coefficients *a, c,* and *e*.

If qualitative sex differences in liability to exercise behavior are present, the genetic correlation for DOS twins should be lower than the genetic correlation for DZ twins. To assess qualitative sex differences the genetic correlation (rg) between DOS twins was estimated and we tested whether fixing rg to 0.5 resulted in a significant deterioration of model fit. Quantitative sex differences in liability to exercise behavior were assessed by allowing the genetic (*a*), shared environmental (*c*), and nonshared environmental (*e*) parameter estimates to differ for boys and girls and we tested whether constraining these parameter estimates to be equal for boys and girls resulted in a significant deterioration of model fit. The statistical significance of the variance components A and C was assessed by testing whether fixing the corresponding parameter estimate (i.e., *a* and *c*) to zero resulted in a significant deterioration of model fit.

We fitted various models that were nested in the sense that one model could be derived from the other by the imposition of one or more constraints on the parameters. The fit of the different models was compared by means of the log-likelihood ratio test (LRT). The difference in minus two times the log-likelihood (-2LL) between two nested models has a χ^2 distribution with the degrees of freedom (df) equaling the difference in df between the two models. If a P-value higher than 0.05 was obtained from the χ^2-test the fit of the constrained model was not significantly worse than the fit of the more complex model. In this case, the constrained model was kept as the most parsimonious and best fitting model. The fit of the genetic models was also compared to the full ACE model by means of Akaike's Information Criterion, keeping the model with the lowest AIC as the best fitting model [22].

3. Results

Table 2 presents the prevalence of exercise behavior for the three-age groups. The table shows that irrespective of age, sedentariness and moderate exercise behavior are more prevalent in girls, whereas vigorous exercise behavior is more prevalent in boys. Formal tests on the thresholds showed these differences to be significant. The thresholds were different between boys and girls in the 13-14 years ($\chi^2(2) = 87.44$, $P < .01$), 15-16 years ($\chi^2(2) = 84.33$, $P < .01$), and the 17–19 years ($\chi^2(2) = 64.03$, $P < .01$) age groups. In boys and girls, there is an increase in the prevalence of sedentariness (i.e., decrease in exercise behavior) in the 17–19 olds compared to the other age groups whereas there is a parallel decrease in the prevalence of moderate exercise behavior. The prevalence of vigorous exercise behavior remains constant throughout adolescence.

Twin correlations in the different age groups are presented in Table 3. For boys and girls, MZ twin correlations were significantly higher than DZ twin correlations in the 13-14 years ($\chi^2(2) = 63.20$, $P < .01$), 15-16 years ($\chi^2(2) = 43.09$, $P < .01$), and 17–19 years ($\chi^2(2) = 23.94$, $P < .01$) age groups, suggesting that individual differences in liability to exercise behavior are influenced by genetic factors. For girls in the youngest age group, resemblance in exercise behavior between MZ twins was similar to DZ twins, suggesting that shared environmental factors play an important role in explaining individual differences in exercise behavior. For girls in the two oldest age groups and for boys in all age groups DZ twin correlations were about half the MZ twin correlation, suggesting that genetic factors explain the bulk of variation in exercise behavior for these age groups.

Genetic model fitting results for all age groups are presented in Table 4. In model 2, rg was constrained at 0.5 which did not result in a significant deterioration of model fit in any of the three-age groups, indicating that the same genetic factors act in boys and girls with regard to exercise behavior.

Model 3 tested whether constraining the parameter estimates of the full univariate ACE model to be equal for boys and girls led to a significant deterioration of model fit. In the youngest age group there appeared to be significant differences in the magnitude of the variance components explaining individual differences in liability to exercise behavior. Therefore, parameter estimates were allowed to differ between boys and girls for this age group. In the two oldest age groups constraining the parameter estimates to be equal between boys and girls did not lead to a significant deterioration of model fit.

Models 4 and 5, tested whether constraining the genetic or shared environmental parameter estimate to zero would lead to a significant deterioration of model fit. Additive genetic effects on individual differences in liability to exercise

Table 2: Prevalence (95% confidence intervals between parentheses) of exercise participation in the different age groups as a function of sex.

	13-14 yr		15-16 yr		17–19 yr	
	Boys	Girls	Boys	Girls	Boys	Girls
Sedentariness	20% (17%–22%)	31% (28%–33%)	24% (21%–26%)	31% (29%–34%)	27% (24%–31%)	38% (35%–40%)
Moderate exercise	40% (39%–41%)	45% (45%–46%)	35% (35%–36%)	45% (44%–45%)	31% (30%–31%)	38% (38%–39%)
Vigorous exercise	40% (37%–44%)	24% (21%–26%)	41% (38%–44%)	24% (21%–27%)	41% (38%–46%)	24% (21%–27%)

Table 3: Twin correlations for exercise participation in each age group (95% confidence intervals added in parentheses).

	13-14 yr	15-16 yr	17–19 yr
MZM	.85 (.79–.90)	.76 (.67–.82)	.73 (.60–.82)
DZM	.23 (.01–.42)	.48 (.32–.62)	.48 (.27–.65)
MZF	.83 (.78–.88)	.83 (.77–.87)	.71 (.63–.78)
DZF	.67 (.56–.75)	.52 (.39–.63)	.34 (.15–.50)
DOS	.32 (.21–.42)	.36 (.25–.47)	.29 (.12–.44)

behavior were statistically significant in all age groups. Shared environmental effects were statistically significant for girls in the youngest age group. In all age groups the LRT tests and the AIC pointed to the AE model as the most parsimonious model, except for girls in the youngest age group in which the ACE model was most parsimonious.

The proportions of variance explained by A, C, and E in liability to exercise behavior of the three-age groups are summarized in Table 5. For boys in all age groups, the proportion of variation in liability to exercise behavior explained by genetic factors ranged between .72 and .85. The remaining variation was accounted for by nonshared environmental factors. For girls in the youngest age group, genetic and shared environmental factors accounted for individual differences in exercise behavior, .38 and .46 respectively. For girls in the two oldest age groups, shared environmental factors did not account for variation in liability to exercise behavior, whereas the proportions of liability explained by genetic factors were .80 and .72.

4. Discussion

In a large sample of Dutch adolescent twins, we found that the prevalence of sedentariness increased during late adolescence compared to early adolescence. At all ages, girls were more often sedentary than boys. When regularly engaged in exercise, girls more often exercised at a moderate rather than a vigorous level. During early adolescence, individual differences in liability to exercise behavior could be accounted for by genetic and nonshared environmental factors for boys, whereas for girls shared environmental factors accounted for a substantial part of the individual differences as well. During middle and late adolescence, genetic influences accounted for the largest part of the variation in liability to exercise behavior for boys as well as girls. No evidence was found for qualitative sex differences in the genetic factors, indicating that the same genetic variants appear to influence exercise behavior in boys and girls.

Our finding that the prevalence of moderate exercise behavior decreased during late adolescence in boys and girls in favor of the prevalence of sedentariness corresponds with the results of other studies [4–6]. The prevalence of vigorous exercise, however, did not change across the three-age groups. This finding is consistent with Van Mechelen et al. [6] who observed a graduate decline in the prevalence of physical activities of mild intensity and nonorganized sports activities, but not in the prevalence of organized sports activities. An explanation for this is that vigorous exercisers have strong intrinsic motivations to exercise leading to continuation of their exercise behavior, whereas moderate exercisers are less intrinsically motivated to exercise making them more likely to become sedentary.

The main aim of the present study was to assess to what extent genetic and environmental factors affect exercise behavior from early to late adolescence. For boys, genetic factors accounted for the major part of individual differences in exercise behavior from early to late adolescence. It has been suggested that genetic influences on exercise ability may explain part of the heritability of exercise behavior [23, 24]. The basic idea is that people will seek out the activities that they are good in. This is particularly true in male adolescents, because being good in sports is an important source of self-esteem for these adolescents and the athletic role model is continuously reinforced by the media [25, 26]. Therefore, genes coding for exercise ability (endurance, strength, flexibility, motor coordination) may well become genes for adolescent exercise behavior.

In contrast to boys of the same age, shared environmental factors accounted for a major part of individual differences in exercise behavior for the youngest girls, whereas from 15 years onwards the influence of these shared environmental factors had completely disappeared in favor of genetic factors. Shared environmental influences may include parents, siblings and peers who make sure the young adolescent girls regularly get to the playing field, and to provide positive feedback on their performance. The extent of positive feedback from parents, siblings and especially from peers may increasingly depend on their genotypes for exercise ability. In short, the shared environment determines exposure and encouragement in early adolescence, but, as for the boys, actual exercise ability will determine whether girls like exercising enough (by excelling in it) to maintain the behavior when the perception of peers increases in relative importance to that of parents during mid and late adolescence. The idea that a single factor like exercise ability is crucial to both boys and girls is reinforced by the fact that the same qualitative genetic variation was seen to underlie the heritability of exercise behavior in boys and girls.

Table 4: Univariate model fitting results for exercise behavior in the three-age groups.

Model	vs	-2LL	df	χ^2	Δdf	P	AIC
13-14 yr							
(1) ACE: sex differences (rg estimated)	—	5482.577	2812	—	—	—	—
(2) ACE: sex differences (rg fixed at 0.5)	1	5482.704	2813	0.127	1	.72	−1.87
(3) ACE: no sex differences (rg fixed at 0.5)	2	5502.510	2815	19.81	2	<.01	13.93
(4)[(a)] CE: boys, ACE: girls (rg fixed at 0.5)	2	5536.641	2814	53.94	1	<.01	50.06
(4)[(b)] ACE: boys, CE: girls (rg fixed at 0.5)	2	5497.697	2814	14.99	1	<.01	11.12
(5)[(a)] *AE: boys, ACE: girls (rg fixed at 0.5)*	**2**	**5483.223**	**2814**	**0.52**	**1**	**.47**	**−3.35**
(5)[(b)] ACE: boys, AE: girls (rg fixed at 0.5)	2	5502.504	2814	19.80	1	<.01	15.93
15-16 yr							
(1) ACE: sex differences (rg estimated)	—	5943.005	2986	—	—	—	—
(2) ACE: sex differences (rg fixed at 0.5)	1	5944.573	2987	1.57	1	.21	−.43
(3) ACE: no sex differences (rg fixed at 0.5)	2	5949.728	2989	5.16	2	.08	.72
(4) CE: no sex differences (rg fixed at 0.5)	3	6024.535	2990	74.81	1	<.01	73.53
(5) *AE: no sex differences (rg fixed at 0.5)*	**3**	**5950.674**	**2990**	**.95**	**1**	**.33**	**−2.33**
17–19 yr							
(1) ACE: sex differences (rg estimated)	—	4455.979	2158	—	—	—	—
(2) ACE: sex differences (rg fixed at 0.5)	1	4455.979	2159	.00	1	>.99	−2.00
(3) ACE: no sex differences (rg fixed at 0.5)	2	4458.120	2161	2.14	2	.34	−3.86
(4) CE: no sex differences (rg fixed at 0.5)	3	4495.737	2162	37.62	1	<.01	21.76
(5) *AE: no sex differences (rg fixed at 0.5)*	**3**	**4458.120**	**2162**	**.00**	**1**	**>.99**	**−5.86**

Note. vs: versus; -2LL: −2 log likelihood; df = degrees of freedom; χ^2 = chi-square test statistic; Δdf = degrees of freedom of χ^2 test; $P = P$-value; AIC = Akaike's Information Criterion; rg = genetic correlation between DOS twins. Most parsimonious models are printed in boldface type.

Table 5: Proportions of variance explained by additive genetic, common environmental and unique environmental factors from the best-fitting models for exercise participation in three-age groups for boys and girls (95% confidence intervals added in parentheses).

		A	C	E
13-14 yr	Boys	.85 (.78–.90)	—	.15 (.10–.22)
	Girls	.38 (.22–.57)	.46 (.27–.61)	.16 (.12–.21)
15-16 yr	Boys	.80 (.76–.84)	—	.20 (.16–.24)
	Girls	.80 (.76–.84)	—	.20 (.16–.24)
17–19 yr	Boys	.72 (.65–.77)	—	.28 (.23–.35)
	Girls	.72 (.65–.77)	—	.28 (.23–.35)

The genetic architecture of exercise behavior during adolescence has been addressed in previous studies [4, 11, 12]. In a sample of the Netherlands Twin Registry from an earlier birth cohort, Stubbe et al. [4] also found a shift from shared environmental to genetic influences during adolescence. However, they reported the shift to occur during late adolescence (i.e., around 16 years) and shared environmental effects on exercise behavior were found not only for young adolescent girls but also for the boys. The sample had very similar age groups as in the present study but the data were collected 10 to 15 years earlier, that is in a birth cohort born 10 to 15 years earlier than the current cohort. The much larger sample size of the present study and its more extensive assessment of leisure time exercise behavior may have led to increased precision of the estimated parameters.

Additional support for the pattern of sex differences in the genetic architecture of exercise behavior in adolescents found in the present study comes from other studies in different countries. In a small Flemish sample of 15 year-old twins Beunen and Thomis [12] found that 83% and 44% of variability in exercise behavior is accounted for by genetic factors for boys and girls respectively, and 54% is accounted for by shared environmental factors only in girls. In a study based on 411 Portuguese twins aged 12–25 years, Maia et al. [11] found larger heritability estimates for boys (68%) compared to girls (40%). Unfortunately, both studies were too small to divide their samples into different age cohorts and it could not be established whether the sex differences were specific to certain age groups.

A limitation of the present study was the use of a cross-sectional twin design to examine the relative influence of genetic and environmental influences on individual differences in exercise behavior. The genetic architecture of exercise behavior during adolescence is most properly addressed in a longitudinal design. So far data at two time points are only available for a small subsample, and data throughout adolescence (13–18) are absent. Since our data collection is a continuous process at the NTR we anticipate large enough longitudinal sample size within the next 5 years. Large shifts in the genetic architecture are expected when subjects move from adolescence to adulthood. In adulthood, nonshared environmental factors become more important and heritability decrease to about 50% [23]. Furthermore significant qualitative sex differences are found in adulthood with different genetic factors influencing male and female exercise behavior [23, 27].

5. Conclusions

The prevalence of moderate exercise behavior declined from age 13 to 19, whereas the prevalence of vigorous exercise behavior remained constant across age groups. Variation in exercise behavior could be largely accounted for by genetic factors, whereas shared environmental factors only accounted for a substantial part of the variation in girls aged 13-14 years. Future studies should focus on the role of exercise ability as a potential determinant of exercise behavior. If the high heritability of exercise behavior in this phase of life is indeed explained by genetic effects on exercise ability—a testable hypothesis—then the relatively high levels of sedentary adolescents may reflect an undesirable emphasis on performance rather than pleasure in current day adolescent sports culture.

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Research Article

Key Beliefs for Targeted Interventions to Increase Physical Activity in Children: Analyzing Data from an Extended Version of the Theory of Planned Behaviour

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Given the high prevalence of overweight and low levels of physical activity among children, a better understanding of physical activity behaviour is an important step in intervention planning. This study, based on the theory of planned behaviour, was conducted among 313 fifth graders and their parents. Children completed a computer-based questionnaire to evaluate theoretical constructs and behaviour. Additional information was obtained from parents by means of a questionnaire. Correlates of children's physical activity were intention and self-identity. Determinants of intention were self-efficacy, self-identity, and attitude. Parental variables were mediated through cognitions. Among girls, practicing sedentary activities was an additional negative determinant of intention. Key beliefs of boys and girls were related to time management and difficulties associated with physical activity. For girls, social identification as an active girl was another important belief related to positive intention. This study provides theory-based information for the development of more effective interventions aimed at promoting physical activity among children.

1. Introduction

In North America, the prevalence of overweight and obese children has increased considerably in recent decades, affecting about one third of youths [1–4]. Although regular physical activity is a healthy way to control body weight, few children are physically active [5–7]. This phenomenon is even more prevalent during adolescence [8, 9], when a major decrease in physical activity levels is frequently observed [6]. Consequently, paying more attention to youths' physical activity behaviour before they give up physical activity could help to prevent this withdrawal.

Results from previous reviews of correlates of physical activity among children revealed inconsistencies in the most important factors related to this behaviour [10, 11]. Moreover, most studies reviewed were not based on sound theoretical frameworks such as the theory of planned behaviour (TPB) [12] or the social cognitive theory (SCT) [13]. Consequently, although a number of interventions have been developed and implemented, results from a recent review of such studies showed that most of the interventions have experienced limited success [14]. According to some authors, the effectiveness of physical activity interventions would benefit from a better understanding of this behaviour [15–17]. Thus, analyzing data from a well-recognized theoretical framework for the identification of intervention targets might prove to be an interesting way to increase physical activity more effectively among children [18–20].

In past decades, the TPB (see Figure 1) has demonstrated its usefulness in studies of health-related behaviour [21, 22], including physical activity [23, 24]. However, a limited number of publications reported applications of this theory among children aged between nine and twelve who have not yet entered high school [25–28]. According to these studies, intention, the core construct of the TPB, has been identified as the principal determinant of physical activity among

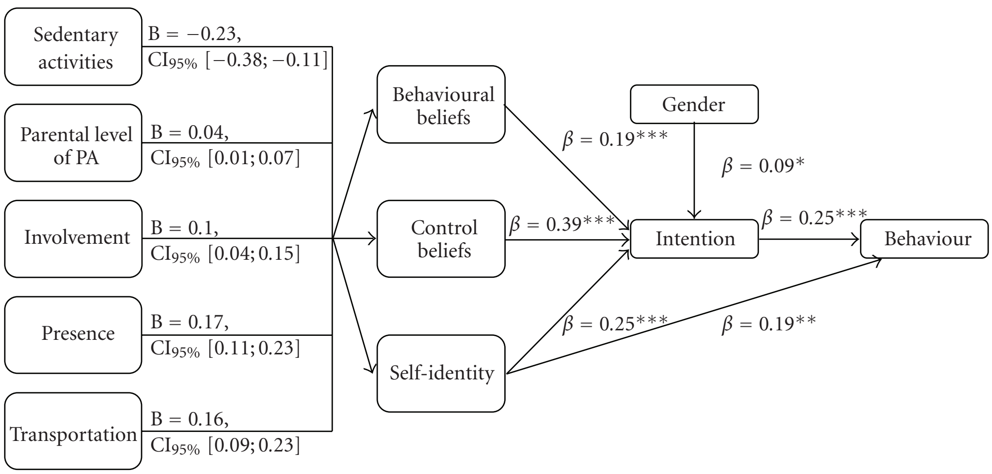

Figure 1: Final model explaining children's physical activity behaviour and intention. $^{*}P < .05$; $^{**}P < .01$; $^{***}P < .001$, B: Estimates; $CI_{95\%}$: Bias corrected and accelerated confidence interval; β: Standardised betas.

children. Thus, in reference to Ajzen's recommendations for the development of interventions based on the TPB [29], the next step is to investigate the determinants of intention and their related beliefs reflecting the cognitive foundation of the targeted behaviour. To our knowledge, no study in the scientific literature has reported which key beliefs should be targeted in community-based interventions aimed at increasing physical activity among children. Thus, the aim of this study was to identify correlates of regular physical activity as well as key elements to guide the development of such interventions.

1.1. Theoretical Framework. This study was based on an extended version of the TPB. According to the TPB, behaviour is predicted by intention and perceived behavioural control when the behaviour is not completely volitional. In turn, intention is predicted by attitude, subjective norm, and perceived behavioural control. Attitude represents the individual's favourable position towards adopting a specific behaviour. Subjective norm is the person's perception of the approval from significant others. Perceived behavioural control is defined as the degree of ease or difficulty with which behaviour can be adopted. Each of these three variables is defined by specific behavioural, normative, and control beliefs. In the present study, only beliefs were assessed, to shorten the questionnaire and because children of this age may not present the cognitive capacities for the abstraction needed to evaluate their behaviour. Also, only beliefs were considered given that they represent potential targets for intervention [30]. In addition to beliefs, other variables known to contribute to the explanation of children's intention or behaviour were also considered (i.e., descriptive norm [31], self-identity [32], and Triandis's concept of facilitating factors [33]). Finally, the influence of direct parental support, parental physical activity level, and body mass index (BMI) as well as children's BMI and past sedentary activities were explored.

2. Methods

2.1. Sample and Procedure. A total of 334 fifth graders and 325 parent-respondents were recruited in six schools of an urban region of Quebec, Canada. Participation rates were 84.3% for children and 82.1% for their parents. After the exclusion of some participants (e.g., technical problems with the computer-based questionnaire, absence the day of data collection, misunderstanding of the questionnaire, no corresponding questionnaires of one parent and outliers), the data of 313 children and their participating parents were retained for analysis.

The computer-based questionnaire was completed by the children during school hours. Between 20 to 30 minutes were devoted to this task. Parents completed their questionnaire at home. The questionnaire was completed by one respondent (i.e., father, mother, or a legal respondent). For participation, written consents of both one parent and the child were obtained. This study was approved by the local University Ethics Committee.

2.2. Children's Questionnaire. The computer-based questionnaire was developed on an *Asus MyPal A620 PocketPC* (Asus computer international, 44370 Nobel Drive, Fremont, CA 94535, EU) to facilitate comprehension, stimulate participation, and maintain children's attention. This questionnaire was developed following Ajzen's guidelines for developing a TPB questionnaire: the measurement of beliefs based on an elicitation study [34]. Accordingly, semistructured interviews took place with 28 children aged from 10 to 11 on perceived advantages/disadvantages, sources of encouragement, and barriers/facilitators regarding physical activity. Thereafter, a content analysis was conducted by two independent reviewers to classify and identify the children's most important beliefs. For each category of salient beliefs, a frequency of mention was established and those which were the most frequently mentioned (up to 75% of the total) were retained. In a second phase, the questionnaire was evaluated by four experts and twelve children to validate the clarity and comprehension of the items. All psychosocial variables were measured on four-point scales: (1) no, not at all; (2) no, not really; (3) yes, maybe; and (4) yes, for sure and showed moderate to good internal consistency and temporal stability over a two-week reliability test (test-retest).

Intention was assessed with the following three items: this week…(1) *will you do physical activities?* (2) *will you try to do physical activities?*, and (3) *what are the chances of you doing physical activities?* ($\alpha = 0.75$ and Intraclass coefficient = 0.71).

Positive behavioural beliefs were assessed by two items: *doing physical activities is*…(1) *fun* and (2) *something to do when I am bored* (Spearman coefficient = 0.24, $P < .0001$). Negative behavioural beliefs were also assessed by two items: *doing physical activities*…(1) is *tiring* and (2) *can cause me bodily injury* (Spearman coefficient = 0.26, $P < .0001$).

Normative beliefs were measured using four items: *do your*… (1) *parents*, (2) *friends*, (3) *other members of your family*, and (4) *teachers encourage you to do physical activities*? ($\alpha = 0.67$ and Intraclass coefficient = 0.70). Descriptive norm was also assessed by four items: *are*…(1) your *friends*, (2) *one of your siblings*, (3) *your father*, and (4) *your mother physically active*? (Intraclass coefficient = 0.63). Self-identity was measured by two items: *do you think you are* … (1) *the sporty type* and (2) *a physically active youth?* (Spearman coefficient = 0.69, $P < .0001$).

In the present study, control beliefs referred to Bandura's concept of self-efficacy [35]. Self-efficacy refers to a child's capacity to overcome perceived barriers to adopt the behaviour. Self-efficacy was assessed by the following four items: *do you think you can do physical activities even if* (1) *they are difficult*?, (2) *you have homework to do*?, (3) *the weather is bad?*, and (4) *you have some others activities to do*? ($\alpha = 0.66$ and Intraclass coefficient = 0.52). Finally, facilitating factors were assessed by mean of eight items: *Is it easier for you to do physical activities if* (1) *you like the physical activities proposed to you*?, (2) *you have equipment at home*?, (3) *your parents enrol you in physical activities*?, (4) *you can do physical activities at school*?, (5) *you have transportation*?, (6) *you are involved in a sports team*?, (7) *your parents encourage you?*, and (8) *you have a friend with you?* ($\alpha = 0.68$ and Intraclass coefficient = 0.48).

Inspired by previous work by Sallis et al. [36], physical activity behaviour was evaluated using a checklist of the most usual sports and physical activities practiced in winter (i.e., the study context). Children had to report if they practiced these activities and how many times they practiced them in the last seven-day period. It was explained to the children that physical activity included any activities or exercise that made them move, breathe hard, and increase their heart rate [37]. Children who reported at least seven periods of physical activity or more were considered active [7, 38]. Finally, children's past sedentary activities were assessed by two items: *yesterday, did you* (1) *watch TV*? (2) *play video/computer games or work on a computer*? Answers were (1) *no*, (2) *yes, for no more than 30 minutes*, (3) *yes, between 30 minutes to one hour*, and (4) *yes, for more than one hour*.

The parents' questionnaire consisted of questions on their regular leisure-time physical activity practices over the last three months [39]. They were also asked to report their weight and height as well as the weight and height of their children. The Body Mass Index (BMI) of parents was estimated using the Canadian guidelines for body weight classification in adults [40] and the BMI of children was estimated using the Cole et al. [41] classification. Finally, parental support for structured activities was measured using the following items: (1) *are you involved in your child's sports organization?*, (2) *are you present when your child is participating in his/her activities?*, and (3) *do you offer transportation to your child?* Scales ranged from no, never (+1) to yes, often (+3).

2.3. Statistical Analysis. Hierarchical multiple linear regression analyses were used in the following sequence to predict physical activity: first, the behaviour was regressed on intention and control beliefs (i.e., self-efficacy and facilitating factors); second, descriptive norm and self-identity were added to the model; finally, the influence of other characteristics was tested (i.e., gender, children's and parents' BMI, direct parental support for structured activities, and past sedentary behaviour). To predict intention, the same procedure was applied: first, intention was regressed on the positive and negative behavioural beliefs, normative beliefs, and self-efficacy; second, facilitating factors, descriptive norm, and self-identity were added to the model; finally, the influence of the other characteristics cited above was tested to predict children's intention to be physically active. According to a recent framework proposed by Kremers et al. [42] for the study of energy-balanced related behaviours (i.e., the Environmental Research framework for weight Gain prevention), environmental factors can either be direct predictors of behaviour or mediated by other theoretical constructs. To test this specific hypothesis, a mediation analysis of variables correlated with intention and its determinants identified in previous analyses was performed using a bootstrapping procedure for multiple mediator models [43].

Lastly, in order to identify potential targets for community-based interventions, an approach proposed by Von Haeften et al. [30] was adopted. This logistic regression analysis allows identification of the most salient beliefs related to different levels of intention. For this analysis, the intention was dichotomised at the median, allowing the discrimination of beliefs explaining a high level of intention versus a low level of intention. First, intention was regressed on the items of its significant determinants identified in the above multiple regression analysis. This operation was completed separately for each set of beliefs. At the final step, all significant items were added in a final model with the remaining significant items representing the most promising intervention targets.

3. Results

3.1. Sample Characteristics. The sample consisted of 161 girls and 152 boys with a mean age of 10.4 ($SD = 0.5$)

Table 1: Hierarchical regression analyses for the prediction of behaviour.

Variables	Model 1	Model 2	Model 3	Final model
Behaviour	Standardised betas (β)			
Intention	0.25***	0.20**	0.22**	0.25***
Self-efficacy	0.14**	0.10	—	—
Facilitating factors	0.04	—	—	—
Descriptive norm		0.00	—	—
Self-identity		0.16**	0.16*	0.19**
BMI (children)			0.01	—
Gender			0.02	—
Involvement			0.02	—
Presence			0.01	—
Transportation			0.08	—
Parents' level of PA			−0.00	—
R^2	0.13	0.14	0.11	0.14

PA: physical activity.

Table 2: Final models of the determinants of intention according to gender.

Variables	Boys	Girls
	Standardised betas (β)	
Self-efficacy	0.49***	0.28***
Self-identity	0.20**	0.28***
Positive Behavioural beliefs	0.20**	0.18**
Sedentary activities	—	−0.13*
R^2	0.55	0.38

years. The percentages of overweight and obese children were 11.6% and 2.5%, respectively. The mean age of their corresponding parents was 41.9 (SD = 4.6) years. The percentages of overweight and obese parents were 32.3% and 7.3%, respectively. In this sample, the mean frequency of physical activity was 15.3 (SD = 6.5) periods in the last week, indicating that children participated in two periods of physical activity per day on average. When examining the type of physical activity performed, results indicated that children were engaged primarily in unstructured activities such as playing ball and playing outdoors; only three children (<1%) reported no involvement in these two activities at least once in the last week. Concerning the level of physical activity of the parents, 37.8% of them reported at least three periods of moderate physical activity per week in the last three months.

3.2. Correlates of Physical Activity. The correlates of children's physical activity were intention to be physically active and self-identity, explaining 14.9% of the variance of physical activity behaviour. None of the other characteristics were significantly associated with children's behaviour (see Table 1).

3.3. Determinants of Intention. The determinants of children's intention to be physically active almost every day of the week were, in order of importance, self-efficacy, self-identity, positive behavioural beliefs, and gender. These four variables explained 47.0% of the variance of intention. The mediation analysis showed that the influence of external variables (i.e., sedentary activity, parental level of physical activity, involvement, presence, and transportation) on children's motivation toward physical activity was mediated by self-efficacy, positive behavioural beliefs, and self-identity, except for parental involvement not mediated by behavioural beliefs (see Figure 1 for the final model). It is noteworthy that the BMIs of children and parents were not correlated with intention and its determinants. Consequently, they were not tested as potential mediating variables.

Because gender had a positive influence on intention, data were reanalyzed separately for boys and girls. The final models for boys and girls were similar, in that self-efficacy, self-identity, and positive behavioural beliefs significantly predicted intention (see Table 2). However, for girls, involvement in sedentary activities was an additional determinant having a negative influence on intention. Nonetheless, the percentage of explained variance was significantly higher for boys than for girls (z = 1.97). Consequently, the analysis of key beliefs was performed separately for boys and girls.

3.4. Key Beliefs for Community-Based Interventions. For girls, key beliefs related to high levels of intention were as well as: (1) *doing physical activities almost every day is fun* (behavioural beliefs), *I can do physical activities almost each day even if* (self-efficacy), (2) *they are difficult* and (3) *I have homework to do*, and finally (4) *do you think you are a physically active youth?* (self-identity). For boys, there were only two important key beliefs defining motivation: *I can do physical activities almost each day even if* (self-efficacy) (1) *they are difficult* and (2) *I have some other activities to do*.

4. Discussion

Results of this study suggest that only children's intention and self-identity explained a small proportion of variance in their participation in physical activities. Nonetheless, this result compared very favourably with previous predictive studies based on the TPB among children [25–28] and give new insight on key beliefs associated with high intention to be physically active. In these previous studies, the explained variance did not reach 10%, except for one study by Rhodes et al. [25], in which 35% and 50% of the variance of behaviour was explained by intention, perceived behavioural control, and past behaviour for the two follow-ups, respectively. None of the parental variables contributed to the prediction of either behaviour or intention. This result is quite surprising, given that many studies have observed the positive influence of multiple dimensions of parental support on children's and adolescents' physical activity behaviour [44–47]. In fact, the results of the mediation analysis suggest that the influence of these variables on children's motivation toward physical activity is mediated by cognitions. Consequently, parental support appears to play a significant role in the development of a high level of self-efficacy, positive attitude, and a perception of being the sporty type or an active youth. Such results confirm previous observations that indicated that environmental factors are mediated by the TPB variables [48, 49]. It is also interesting to note that self-identity towards being the sporty type and an active child plays a significant role in explaining behaviour as well as intention. This suggests that promoting a positive image of being an "active" youth could be an effective way of encouraging participation in regular physical activity.

The importance of intention suggests that educational strategies aimed at increasing children's motivation remain an important strategy to promote physical activity. To increase motivation, however, some additional information from the structure of beliefs is required. Results of the present study suggest that the strategies adopted should be different for girls than for boys. Indeed, a deeper analysis of their key beliefs revealed that although two of the important barriers to physical activity were similar for boys and girls (i.e., perceived difficulty and time management), the cognitive foundation of the motivation toward physical activity was slightly different. Indeed, for girls, having fun while participating in physical activities and perceiving themselves as active individuals were two additional significant elements associated with positive intention, whereas these two aspects were not salient for boys. Consequently, parents and physical educators should make sure that girls have positive experiences with physical activity. It would be important to facilitate access to a variety of activities allowing girls to discover physical activities in line with their personal interests and in which they can excel. The creation of contexts in which children, and girls in particular, have the possibility to explore a set of physical activities and choose their favourite could stimulate more enthusiastic participation. In this study, the activities most often reported for girls were playing outside (99%), dancing (73%), playing ball (72%), and skating (68%). It was also observed that the frequency of sedentary activities was negatively associated with physical activity in girls but not in boys. Decreasing time spent in sedentary behaviour has been proposed as an effective strategy to increase level of physical activity in youths [50, 51]. In the context of the present study, it appears that promoting a decrease in sedentary behaviour would prove effective among girls only, given that the motivation of boys toward physical activity is not influenced by watching TV and playing video/computer games or working on a computer.

Children who perceived having many other activities or homework to do demonstrated less intention to be physically active. This observation supports the idea that the allocation of priority periods during or after school and on weekends, when children could be physically active, should help to increase their motivation towards physical activity. To minimize difficulties related to the physical activities, it would be determinant that children develop and practice skills during physical education classes. Indeed, physical education is taught to create a positive social environment, especially for girls, and to facilitate skills and confidence for physical activity in children. Hence, the acquisition of such skills could increase children's feelings of competence and, as such, enjoyment. Also, using some of Bandura's strategies aimed at increasing self-efficacy such as increasing gradually the level of difficulty could help children to develop feelings of mastery of physical activities, thereby increasing their perception of self-efficacy [13].

The above suggestions for the promotion of physical activity among children are likely to be effective. Indeed, a recent mass media campaign (the VERB campaign), aimed at promoting physical activity among children aged from 9 to 13 years and developed and tested by the Centers for Disease Control and Prevention (CDC), showed positive results. This mass media intervention, based on TPB and SCT, was designed to encourage playing, promote physical activity as fun, cool, and socially appealing behaviour, and to provide abilities to overcome barriers to physical activity [52]. After one year, their results indicated that children who were aware of the campaign were involved in 34% more free-time physical activity periods than children who were not aware of the campaign [53]. Also, children exposed and aware of the campaign remained more active and had more positive attitudes toward physical activity behaviour after follow-up two years later [54].

Traditionally, environmental variables have not received much attention within the TPB framework. In this study, the implication of parents in their children's sports organization was analyzed. Although none of the parental variables (i.e., involvement, transportation, presence, and physical activity level) and children's related perception (i.e., facilitating factors) of environmental variables were significant correlates of children's physical activity, this study provides some explanations for this lack of direct environmental influence. Indeed, the mediation analysis provided results well aligned with previous observations that environmental variables could be mediated by intention or self-efficacy rather than having a direct effect on behaviour [45, 55]. In this respect, this study has added information regarding the interplay among environmental factors (family-related factors) and cognitions. However, more research is still needed to understand the relationships between environmental factors, psychosocial variables, and children's physical activity behaviour.

Finally, some limitations of this study must be noted. First, although Rhodes and Plotnikoff [56] documented the relevance of proxy measures of physical activity as an expression of future or current physical activity behaviour, a longitudinal study would allow stronger conclusions regarding the direct predictors of children's physical activity or the moderating effects of environmental factors on this behaviour. Secondly, all information was self-reported. Consequently, because children are sensitive to social desirability bias [57], they could have responded more favourably to psychosocial variables and overestimated their physical activity participation. Finally, these findings should not be generalized to the child population, since the study was conducted among a convenient sample recruited in specific schools.

To conclude, the present study provides promising theory-based information on ways better to promote the regular practice of physical activity among children. In particular, emphasis should be placed in the development of self-identity regarding physical activity and the development of children's motivation by focusing on the management of specific barriers to physical activity such as time management associated with conflicting activities and the perceived difficulty of physical activities. Also, it is important to ensure that girls have positive experiences in physical activity and identify themselves as active young girls.

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Research Article

Parental Influence on Young Children's Physical Activity

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Parents influence on their young children's physical activity (PA) behaviours was examined in a sample of 102 preschool-aged children (54 boys). Questionnaires regarding family sociodemographics and physical activity habits were completed. Results showed that children who received greater parental support for activity ($B = .78$, $P < .10$) and had parents who rated PA as highly enjoyable ($B = .69$, $P < .05$) were significantly more likely to engage in one hour or more of daily PA. Being an older child ($B = -.08$, $P < .01$), having older parents ($B = -.26$, $P < .01$), and watching more than one hour of television/videos per day ($B = 1.55$, $P < .01$) reduced the likelihood that a child would be rated as highly active. Children who received greater parental support for PA were 6.3 times more likely to be highly active than inactive ($B = 1.44$, $P < .05$). Thus, parents can promote PA among their preschoolers, not only by limiting TV time but also by being highly supportive of their children's active pursuits.

1. Introduction

It is widely accepted that physical activity has numerous positive health outcomes including its influence on meeting healthy weight goals, when associated with low-energy intake through healthy eating habits [1–4]. In children, physical activity is particularly important as it improves gross and fine motor skill development necessary for academic performance (e.g., writing), self-perceived competence (academic as well as athletic) as well as increasing socioemotional adjustment and self-esteem [5]. Physical activity in groups and games also have social benefits in that they offer children opportunities to learn new skills [6] while developing friendships [7].

Physical activity is defined as any physical movement resulting from skeletal muscle contraction [8]. In contrast, sedentary activities can include watching TV/videos, playing video games, computer time, and reading. According to Social Learning Theory [9], individuals learn their habits and attitudes toward PA very early in their development, by observing and imitating their parents. According to Welk, Wood, and Morss [10], there are two aspects of parental behaviours that promote PA in children: (1) role modeling, which includes a parent's interest in PA as well as their efforts to be active, and (2) parental support, which refers to parental encouragement, involvement (i.e., participating in PA with the child), and facilitation such as providing access and opportunities for the child to be active (e.g., transportation to arenas and parks).

Supporting the importance of parental support and role modeling in their children's PA habits, research suggests that there is a link between parental PA [11], encouragement, involvement/interaction, support [12–14], and their children's PA. Moore et al. [11] found that children between 4 and 7 years of age were 3.5 to almost 6 times more likely to be active when one or both parents were active than when both parents were inactive. Among the various components of parental influence, it appears that parental facilitation exerts the greatest independent influence on young children's PA [10]. In addition, there is evidence that parental support of child PA contributes to the maintenance of PA habits later in adolescence, at least in girls [15].

Researchers have suggested that the benefits of PA on health are moderated by sedentary behaviors; however, findings are inconsistent. For example, Proctor at al. [16] and Janz et al. [17] found that children who watched the most TV and who were the least physically active had the greatest increases in body fat from preschool to early adolescence whereas children who were active and watched little TV gained the least. On the other hand, Hinkley et al.'s [12] literature review found that about half of the studies examined reported no association between PA and sedentary behaviours. As such, there is an ongoing need for more research in this area, if only to better understand the relationship between PA and TV viewing in young children.

As with any other type of learning, parental role modeling does not entirely explain children's development of PA habits. Research has also demonstrated the salience of personal, familial, and environmental factors that influence both physical activity and sedentary behaviors in children. Among personal factors, a number of authors have found that boys are more active [12, 18], and that they engage in more vigorous activity than girls [19, 20]. There is also an age-effect among preschool children, with some studies indicating reduced physical activity levels between the ages of 4 to 5 years compared to during the third year of life, for both boys and girls [20, 21]. Weight status does not seem related to the activity levels of preschoolers according to a review by Hinkley et al. [12].

Among familial characteristics that influence children's physical activity are parents' education level and income [12, 18, 22]. Little is known about the influence of parents' marital status on activity and the sedentary habits of their young children. According to Hinkley et al. [12], single-parent status has not been examined as a potential correlate of PA in preschoolers. Time spent outdoors as well as access to play areas and facilities are two of the most commonly investigated physical environmental factors associated with PA and both have been positively associated with increased levels of PA among preschool-aged children [12, 18, 23, 24].

Despite the aforementioned predictors of early development of PA habits, there are very few studies conducted with very young children. Timmons et al. [23] suggested that the underrepresentation of preschoolers in study sampling may be based on the erroneous assumption that young children are sufficiently physically active. These misperceptions might be explained by the lack of specific physical activity recommendations for children under 6 years of age, as is the case in Canada [25]. In general, it is recommended that preschoolers accumulate at least 60 minutes of structured (organized) PA and 60 minutes of unstructured (informal) PA per day [26] and that TV viewing be limited to one hour per day for preschoolers [27]. Research shows that Canadian children between the ages of 2 and 11 years watched an average of 2 hours of TV per day [28]. It has been shown that preschoolers do not typically engage in PA for consecutive minutes; instead, they tend to engage in brief bouts of movement and spend little time at vigorous intensity levels [23]. Other researchers have demonstrated that preschoolers spend most of their free-play or unstructured time engaged in sedentary activities [29, 30]. When they are not idle, researchers have found that their activity levels do not meet recommended thresholds. Rather, they are most likely to engage in only 32 minutes of activity during 2-hour stints of outdoor playtime [30]. In short, findings have not supported the commonly held belief that preschoolers are highly active.

It would appear that no research has examined the combined effect of parental influence as well as child and family characteristics on the PA and sedentary behaviors of preschool children. Moreover, few efforts have targeted parental attitudes toward PA, particularly in samples of very young children. This is unfortunate since parental enjoyment of PA is likely a strong determinant of such in their children. Also, no studies have considered parental perceptions of their preschoolers PA. Consistent with findings that a large proportion of parents fail to recognize overweight or obesity in their children [31–33], parents who perceive that their child's level of PA is sufficient are less likely to apply what they have learned in prevention programs regarding eating behaviours and physical education [32]. Therefore, measuring parents' perceptions of their child's PA levels is relevant.

With this in mind, the main objective of this study was to examine the influence of parents on their children's PA. The links between their enjoyment of PA, the degree of importance they assign to their child's PA abilities and their support of PA habits on their preschool-aged children are also explored. A secondary objective was to determine which child characteristics (e.g., age, gender, TV/Video viewing, weight status and linguistic group) and parent characteristics (e.g., income, education, age, marital status and weight status) best predict PA.

2. Method

2.1. Procedure. This study is a part of a larger project conducted between January and September 2008, which examined individual and family factors associated with preschool children's overweight and obesity levels using parent, child, and teacher interviews and questionnaires. The BMI was calculated for participants and served as an indicator of subjects' levels of overweight and obesity. Consent was sought for all aspects of the study.

Twenty-six licensed, centre-based, child care facilities in the City of Greater Sudbury (Ontario, Canada) were contacted. The centres were selected from different neighborhoods within the city and surrounding areas to provide a sample that represented the broad range of socioeconomic, ethnic and linguistic (primarily French and English) backgrounds found in the region. When the authorization of the day cares were obtained, the research assistants distributed consent forms along with a letter explaining the study to parents of all children between the ages of 3 and 5 years at each of the participating child care centres. One hundred and two parent-child dyads gave their consent for themselves and their child to be interviewed. They were also asked to give their consent for the daycare worker to answer a questionnaire about their child's physical activity. Parents received $10 for their participation. The study was approved by the university's Research Ethics Board where the authors are employed.

2.2. Participants. Fifty-four boys (52.9%) and 48 girls (47.1%) between 3 and 5 years of age (M = 3.75 years; SD = .80) and their parents (mean age = 34.0 years; SD = 7.0) participated in this study. Forty-nine children were three years of age (46.7%), 33 were four years of age (31.4%), and 23 were five years of age (21.9%). An equal number of child-parent dyads were recruited from French and English-speaking child care centres ($n = 53$). Almost all of the parents responding to the questionnaires were women ($n = 98$). Only 4 parent respondents were men. The majority of parents were married ($n = 74$, 72.5%), while approximately one-quarter were single, separated, or divorced ($n = 28$, 27.5%). Family income level was categorized as low ($49 999 or less), middle ($50 000 to $74 999), and high ($75 000 and above). Nearly half of the families had an annual income of $75 000 or more ($n = 46$, 47.9%) while 21 (21.9%) and 29 (30.2%) were classified in the middle and low-income groups, respectively. Thirty-nine parents (38.6%) reported that they had completed postsecondary education.

2.3. Instrument. The questionnaires were designed specifically for the purpose of this study. Some questions and variables were adapted or taken from pre-existing questionnaires while others were created by the research team. A bidirectional translation method was used to translate the questionnaires from English to French (i.e., the questionnaires were translated then verified by members of the research team). The questionnaires were pretested by adults in both languages. The questionnaires administered to the parents sought child characteristics (e.g., age and gender), the average amount their child watches TV or videos each day, the child's daily physical activity (PA), their perception of the intensity of their child's PA, parent characteristics (e.g., gender, marital status, household income, and level of education), and parental PA behaviours and attitudes. The items selected for the study are described in the following paragraphs.

2.4. Dependent Variables

2.4.1. Child Daily PA. Parents were asked to indicate the total amount of time, on average, their child participated in daily physical activity (e.g., sports) and/or physically active play (e.g., playing tag or climbing on a gym set). The items were rated on a four-point Likert scale as follows: (1) "less than 30 minutes per day", (2) "30 to 60 minutes per day", (3) "60 to 120 minutes per day", and (4) "120 minutes or more per day". As per PA recommendations [26], child daily PA was then dichotomized into either one hour or more of PA per day or less than one hour of PA per day. Three quarters of the children (75.5%) participated in at least one hour of daily PA; however, considerably more boys (83.3%) than girls (66.7%) achieved the recommended duration of PA, χ^2 (1, $N = 102$) = 3.82, $P < .05$.

2.4.2. Parent's Perception of Intensity of Child Activity. In addition to the amount of time children spent engaged in daily physical activity, parents were asked to rate their perception of the intensity of their child's activity at different times during the day: before breakfast, morning, early afternoon, late afternoon, and after dinner. A five-point Likert scale was used: (1) "not at all active", (2) "slightly active", (3) "moderately active", (4) "very active", and (5) "highly active". An overall average activity level was computed for each child from these five items then categorized into three groups as follows: inactive (an average score < 3.0), moderately active (an average score ≥ 3.0 and < 4.0), and highly active (an average score ≥ 4.0). The majority of children were considered moderately active (58.8%). Another 14.7% were considered highly active and about one quarter of the sample (26.5%) was deemed inactive. No significant gender differences were found among the three groups χ^2 (2, $N = 102$) = .55; $P = .76$.

To assess the criterion concurrent validity of this measure [34], daycare workers were asked to report on their perceptions of the activity level of each child. The questions for daycare workers were similar to those used with parents but included only three time periods (morning, early afternoon, and late afternoon) to reflect the timeframe when children were typically at the centres. The scale was identical to that used for the parent questionnaire. The mean for the 3-item scale was computed and compared to the mean rating reported by parents using a paired samples t-test. The results revealed that perceived child activity level ratings did not significantly differ between parents and daycare workers, $t(98) = .28$, $P = .78$, demonstrating good concurrent validity in this sample. For both measures (parents and teachers) the Cronbach alpha reliability coefficients were moderate, that is .64 and .67, respectively. Higher scores were not expected as physical activity naturally varies during the day according to the schedule (period of structured inactivity at school, mealtime, or other activities at home).

2.5. Measures of Predictor Variables

2.5.1. Child Characteristics. Parents completed a questionnaire that sought their child's date of birth, gender, and the time spent by their child watching TV or videos each day ("TV time"). The Canadian Paediatric Society [27] recommends that TV viewing for preschoolers be limited to one hour per day. Based on this guideline, TV time was simply dichotomized as one hour of TV time or less per day or more than one hour of TV time per day. Only half the children (45.4%) in the study engaged in more than one hour of daily TV time. No significant gender differences in the amount of TV time were observed, χ^2 (1, $N = 99$) = .14, $P = .43$.

2.5.2. Child Weight Status. Weight status for each child was determined using the body mass index (BMI). Each child was classified in one of the two following categories: "underweight/normal weight" (< 85th percentile), or "at-risk of overweight/overweight" (≥ 85th percentile) [35]. Overall, twenty-eight children (28.0%) were either overweight or at-risk of overweight and 72 children (72.0%) were considered normal weight. There were no significant gender differences in the proportion of children who were overweight/at-risk of overweight and those of normal weight, χ^2 (1, N = 100) = .16; P = .43.

2.5.3. Parent Characteristics. Parents reported their age, gender, marital status, household income and level of education. Similar to the protocol for children, parents' height, and weight were measured by the researchers and used to calculate their BMI. The mean BMI for the parents was 27.0 (SD = 6.01). According to the Center for Disease Control and Prevention [35], about half of the parents in the study were either overweight (23.3%) or obese (30.2%). None of the parents were underweight and 46.5% were classified as normal weight.

2.5.4. Parental Physical Activity Behaviours and Attitudes. Parents reported on their physical activity behaviours and attitudes. The items were drawn from scales used in the Amherst Health and Activity Study [14]. The variables included parents' support for children's PA, parents' PA (i.e., role modeling), parents' enjoyment of PA, and the importance parent's placed on the child's PA abilities.

2.5.5. Parental Support for PA. Five questions assessed how often during a typical week adults in the household provided the child with support for physical activity (i.e., encouraged the child to be active, participated in PA with the child, provided transportation for the child to go somewhere to be active, watched the child engage in PA, or told the child that PA was good for his/her health). A five-point Likert scale consisted of the following: (0) "none", (1) "once", (2) "sometimes", (3) "almost daily", and (4) "daily". The responses from each adult for the five items were averaged and a combined parent/adult mean score was then computed (M = 2.81, SD = .69). The internal consistency of "parental support for PA", measured by Cronbach's alpha, was 0.75. This finding was similar to that obtained by Trost and colleagues [14], 0.78, in a study that used the same scale with parents of older children (grades 7 through 12).

2.5.6. Parental PA. A three-item measure assessed the frequency of the parents' physical activity habits. Parents were asked how often in a typical week they "walked for exercise", "participated in sporting activities for at least 20 minutes that made them sweat and breathe hard", and "did heavy house cleaning, gardening or yard work for at least 20 minutes at a time". Similar to the "parental support" measure, an average combined score from the parents was computed for the "parental PA" variable (M = 2.80, SD = 1.26).

2.5.7. Parental Enjoyment of PA. With a single item on a five-point Likert scale ranging from (1) "not enjoyable" to (5) "very enjoyable", parents were asked to indicate how much the adults in the family "enjoy physical activity or exercise". A combined average score for the parents was calculated (M = 4.19, SD = .84).

2.5.8. Importance of Child's PA Ability. Parents also reported how important it was to each adult in the household that the child was "good at sports and physical activities" on a five-point Likert scale ranging from (1) "very unimportant" to (5) "very important". Again, the scores from the adults were averaged to create a composite score (M = 3.54, SD = 1.20).

3. Results

3.1. Statistical Analyses. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS Version 15.0). Logistic and multiple regression analyses using child characteristics, parent characteristics, and parents' physical activity behaviours to predict the reported child daily activity and the parent's perceived intensity of a child's physical activity were performed.

3.2. Predicting Children's Daily PA. Logistic regressions were performed to predict child daily PA from child characteristics (first model), parent characteristics (second model), and parental PA behaviours (third model). The results are shown in Table 1.

The test of the full model predicting child daily PA with all child characteristic predictor variables was significant, χ^2 (5, N = 97) = 18.4; $P < .01$, with a goodness of fit of χ^2 (8, N = 97) = 8.04, P = .43. Overall, 83.5% of the cases were accurately predicted. Of the child characteristics, only watching less than an hour of TV/videos per day significantly predicted whether children participated in the recommended amount of daily physical activity (one hour). In fact, children who watched less TV were 4.7 times more likely (B = 1.47, $P < .01$) to participate in sufficient PA. However, it should be noted that children's age and gender approached significance levels. Specifically, male children were almost 3 times more likely to meet recommended levels than girls (B = 1.08, $P < .10$) and children were slightly less likely to be active for at least an hour a day with each month increase in age (B = −.04, $P < .10$).

In the second model, the test of the full model predicting child daily PA from parent characteristic predictor variables (e.g., age, marital status, income, and education) was not found to be significant χ^2 (5, N = 96) = 4.82, P = .44. The goodness of fit obtained was χ^2 (7, N = 96) = 13.1, P = .07.

For the third model predicting child daily PA from parental PA predictors, the test of the full model was significant, χ^2 (4, N = 99) = 23.1; $P < .01$, with a goodness of fit of χ^2 (8, N = 99) = 7.28; P = .51. Overall, 77.8% of the cases were accurately predicted. Among the four parental PA variables, only parental enjoyment of PA significantly predicted child daily PA, whereas parent's support and PA habits approached statistical significance. The more parents supported their child's activity (B = .780, $P < .10$) or the more active the parents (B = .482; $P < .10$) or the greater their enjoyment of PA (B = .697; $P < .05$), the more likely the children were to engage in the recommended amount of daily activity. The importance parents placed on their child's PA abilities did not predict the outcome variable of interest.

Table 1: Logistic regression predicting child daily PA.

Predictors	Beta (SE)	Wald	Odds ratio	Chi-Square χ^2
Child Age (months)	−.044 (.024)	3.58	**.956***	
Child Gender (male)	1.075 (.552)	3.78	**2.93***	
Linguistic Group (French)	.382 (.567)	.454	1.465	
TV Time (1 hr or less/day)	1.555 (.562)	7.65	**4.74*****	
Child At-risk of Overweight/Overweight	.171 (.620)	.076	1.187	**18.37*****
Parent Age (years)	−.034 (.034)	1.010	.966	
Married	−.869 (.695)	1.567	.419	
Income 0–45 K	−.560 (.745)	.565	.571	
Income 45–75 K	−.029 (.746)	.001	.972	
Postsecondary Education	.305 (.723)	.178	1.356	4.82
Parental Support for PA	.780 (.432)	3.25	**2.18***	
Parental Enjoyment of PA	.697 (.341)	4.19	**2.01****	
Parental PA Habits	.482 (.251)	3.69	**1.620***	
Importance of Child's PA Ability	−.034 (.260)	.017	.966	**23.1*****

*$P < .10$; **$P < .05$; ***$P < .01$.

3.3. Predicting the Parents' Perceived Intensity of a Child's PA. A multiple logistic regression analysis was performed to predict child PA intensity level from child and parent characteristics and parental PA behaviours. Child PA intensity levels were categorized into three groups: inactive, moderately active, and highly active. The results are presented in Table 2 with the highly active and moderately active groups displayed and the inactive group shown as the reference category. Similar to prior logistic regression analyses conducted in this study, child characteristics were used in the first model, parent characteristics in the second model, and parental PA behaviours/attitudes in the third model.

The test of the full model predicting child PA intensity levels using child characteristic predictor variables was significant, χ^2 (10, $N = 97$) = 20.3; $P < .05$, with a goodness of fit of χ^2 (166, $N = 97$) = 142.2; $P = .91$. Overall, 66.0% of the cases were accurately predicted. Only child age significantly predicted PA intensity level with older children being slightly less likely to be highly active ($B = -.11$; $P < .01$) or moderately active ($B = .08$; $P < .01$) than inactive for each month increase in age. As shown in Table 2 , none of the other child variables such as gender, linguistic group, TV time, or weight status significantly predicted PA intensity levels.

In the second model, the test of the full model predicting child activity level from the parent characteristics versus the constant-only model was also found to be significant, χ^2 (10, $N = 96$) = 23.9, $P < .01$, with a goodness of fit of χ^2 (112, $N = 96$) = 102.4, $P = .73$. Overall, 61.5% of the cases were accurately predicted. Parent age was found to be the only significant predictor. Children of older parents were less likely to be highly active ($B = -.27$; $P < .01$). Marital status, parent education, and household income did not significantly predict child PA intensity level in this sample.

For the third model, the test of the full model predicting child activity level from parental PA behaviours versus the constant-only model was significant, χ^2 (8, $N = 99$) = 19.6; $P < .05$, with a goodness of fit of χ^2 (186, $N = 99$) = 164.6; $P = .87$. In this model, 60.6% of cases were accurately predicted. Among the parental PA behaviour variables, parental support for PA and parental PA significantly predicted child PA intensity level. Children of parents who provided greater support for PA were over 4 times more likely to be highly active ($B = 1.44$; $P < .05$). Greater parental PA also increased the likelihood that children would be highly active ($B = .68$, $P < .05$) almost two-fold.

4. Discussion

Using a representative sample of Canadian parents, the current study examined the variables that best predicted the PA behaviours of their children. While social learning theory predicts a strong link between parental role modeling of PA and the performance of this behaviour by their offspring, the extant literature has insufficiently considered the relative influence of other predictors of PA within the same study including parental support for PA, parental enjoyment of PA, and the importance parents assign to their children's PA abilities. Moreover, research of this nature has largely overlooked younger age groups of children. With this in mind, parental influence on the PA habits of 102 male and female preschool-aged children was examined. In addition to direct parental influence, this study also considered the effect of child characteristics (e.g., weight status, the amount of television watched) and adult characteristics (e.g., age, marital status, income, education, attitudes) on the intensity and frequency of PA. The discussion that follows below presents the reader with an overview of the study's main findings, while highlighting the particular relevance of parental habits, parental support of PA, and parental enjoyment of PA on their children's PA.

Table 2: Multinomial logistic regression predicting parents' perception of their child PA intensity level.

Predictors	Highly Active Beta (SE)	Highly Active Wald	Highly Active Odds Ratio	Moderately Active Beta (SE)	Moderately Active Wald	Moderately Active Odds Ratio	Chi-Square χ^2
Child Age (months)	−.113 (.038)	8.73	**.893*****	.079 (.023)	11.39	**.924*****	
Child Gender (male)	.676 (.772)	.767	1.967	.116 (.516)	.050	1.123	
Linguistic Group (French)	.325 (.747)	.190	1.384	.204 (.532)	.147	1.226	
TV Time (1 hr or less/day)	.303 (.749)	.163	1.354	−.283 (.523)	.420	1.404	
Child At-risk of Overweight/Overweight	−.064 (.798)	.006	.938	.339 (.565)	.251	.754	**20.3****
Parent Age (years)	−.266 (.095)	7.81	**.766*****	−0.19 (.038)	.252	.981	
Married	.808 (.985)	.672	2.243	.193 (.670)	.083	1.213	
Income 0–45K	.611 (1.205)	.257	1.842	.134 (.764)	.031	1.144	
Income 45–75K	−.259 (1.052)	.061	.772	−.756 (.618)	1.497	.469	
Postsecondary Education	−1.486 (1.378)	1.164	.226	−.165 (1.132)	2.125	.192	**23.9*****
Parental Support for PA	1.441 (.733)	3.86	**4.22****	.478 (.376)	1.614	1.613	
Parental Enjoyment of PA	.458 (.548)	.699	1.58	.080 (.300)	.071	1.083	
Parental PA Habits	.680 (.315)	4.67	**1.974****	.227 (.217)	1.09	1.255	
Importance of Child's PA Ability	−.145 (.306)	.225	.865	.066 (.228)	.085	1.069	**19.56****

*$P < .10$; **$P < .05$; ***$P < .01$.

By way of summary, approximately three-quarters of the children in this study were reported to participate in at least 1 to 2 hours of PA per day. This seemingly high-participation rate can be explained in part by policies that oblige Canadian child care centres to provide children at least two hours each day (weather permitting) of outdoor play to children over the age of thirty months, [36]. Parents may be aware of these standards and assume that their child is participating sufficiently in PA. However, while it may seem that preschoolers engage in sufficient activity, previous researchers have pointed out that the majority of time spent in these play periods are spent in sedentary or light activity [29, 30]. Thus, children may actually be getting much less exercise than their parents believe if they rely solely on day cares to provide such. Of concern is that approximately 27% of children in the current study were considered by parents as generally inactive.

While the majority of children in the current study met the one-hour requirement of daily PA (75%), almost half of the sample (45%) watched more than the one-hour maximum of TV viewing per day recommended by the Canadian Pediatric Society [27]. Moreover, TV watching emerged as one of the strongest predictors of child daily PA. On the other hand, and contrary to previous research showing that TV watching is associated with higher BMI in preschool children [16, 37], we did not find that a child's weight associated itself strongly with their daily PA. This appears to be in line with research by Jago and colleagues [37], who noted that the association between TV watching and BMI emerges only at around 6 years of age. All of the participants in the current study were below 6 years of age and therefore it may be that children in this study were still too young for this association to have emerged.

It was found that different sets of factors predicted child daily PA (binary logistic regression) and child activity levels (multinomial regressions). TV time and parents' enjoyment of PA were the only significant predictors of children's daily PA whereas age (child and parent), parental support of PA, and PA habits predicted children's membership in two of three categories of perceived intensity of PA; that is, highly active or moderately active. Because child daily PA is a measure of the amount of time a child spends engaged in physical activities and the child's PA levels is a qualitative measure of PA, it is possible that parents used different criteria to assess these two components. In other words, it may be the case that parents estimated their child's daily activity on the basis of their knowledge of the child's routine. It follows that related measures such as TV time and enjoyment of PA (which is likely to be associated with families' PA and leisure time) predicted the child's PA. On the other hand, parents' assessment of the child's level of PA may depend on their perception of the child's level of development (younger children requiring more supervision and care might be perceived as more active), and perception of their supportive behavior of PA including their own level of PA.

Results showing that less time watching TV predicted the recommended amount of daily PA might simply illustrate the point that time spent watching TV leaves less time for children to be physically active. On the one hand, it is unlikely that parents would intentionally want their child to be sedentary instead of active. Rather, parents might encourage more TV time in their young children because, as reported by He and colleagues [38], they use TV as a coping tool and babysitting technique so that they can tend to household chores such as cooking and cleaning. On the other hand, studies have also pointed out that the same child can be both highly sedentary and highly active [39]. The results from multiple regression analyses for children's PA intensity levels support this possibility. In short, TV time did not significantly predict whether children were highly active or moderately active versus inactive, despite the fact that it influenced the amount of children's daily PA. Thus, it seems plausible that some of the children in this study watched a lot of TV but were still considered highly active by their parents. Conversely, children who watched very little TV may still have been considered inactive if they spent a lot of their time in other sedentary pursuits such as playing with toys, puzzles, or doing arts and crafts.

Among measures of parental attitudes, only the importance they confer to their child's PA abilities failed to predict child daily PA or PA intensity levels. It is expected that a parent will naturally wish a child to gain new skills and abilities and to be successful in any activity he or she may engage in. However, parents might not see the importance of ability for children who are that young or they may simply accept that such abilities develop later. Parental enjoyment of PA, their PA habits as well as the support they offer their children in their pursuit of PA were cogent predictors and certainly underline the importance of social learning.

Child age and gender were marginally significant predictors ($P < .10$) of daily PA. Older children were slightly less likely to get sufficient PA and boys were almost 3 times more likely to engage in at least an hour or more of PA per day. The results parallel existing research showing that boys are consistently more active [12, 18], and engage in more vigorous activity than girls [19, 20]. Younger children are also more active and less sedentary [20, 21]. Using multiple regression analyses to predict PA intensity levels, older children were significantly less likely to be identified as highly active compared to inactive. Together, the findings of a decrease in activity with an increase in age may be largely explained by the fact that older preschool children are more likely to spend more time at the child care centre preparing for the transition toward more academics in the elementary school setting. Pate et al. [40] suggested that as children get closer to full-time school attendance, the structured, preacademic activities of the older preschool child's classroom outweigh the free play typically seen in classrooms of younger children.

The current study is one of the few in the extant literature that has scrutinized parental influence of PA behaviours (both mother and father) on children's PA habits. The majority of studies on childhood PA have focused on school-aged children while few have focused on the PA patterns of preschoolers. This developmental period is key in the foundation of healthy habits such as being active on a regular basis. Thus, investigating factors that can encourage children to be active from a young age is an important component in combating childhood obesity. Finally, very few studies have looked at the importance parents place on their child's PA ability, particularly in this young age group. This particular variable was not found to be an important predictor of children's PA and an unlikely candidate for further inquiry.

Some results should be interpreted with caution. First, the cross-sectional design does not permit causal inferences between PA outcome variables and predictor variables. It remains unclear if parents who provide a highly supportive environment for their child to be active cause the child to become more active or if it is an active child that influences the degree to which parents provide support for his or her active pursuits. Another limitation of the study was the use of self-report methods to assess child PA rather than using objective measures such as direct observation or accelerometry. The costs of such methods were prohibitive for the current study; however, a number of steps were taken to strengthen the validity of the findings. For instance, we asked both parents and daycare workers to report on two aspects of child PA—their daily amount of PA and each child's overall activity level for different timeframes throughout the day. This provided a more comprehensive understanding of preschool children's overall PA habits. Chen and colleagues [41] found that nursery school teacher's ratings of child activity levels, a measure that was similar to that used in the current study, was a valid method for assessing child PA when compared with two objective monitoring devices. Further, Noland and others [42] examined the validity of the same measure of child activity level used in this study and found a moderate correlation between parent- and teacher-reported child activity levels. Since comparisons between the parent and daycare worker activity level scores in this study did not significantly differ, we can conclude that the PA assessment measures were reasonably accurate reflections of children's PA habits.

5. Conclusion

In summary, parents occupy a privileged position in terms of influencing their children's physical activity. First, they are the custodians of daily schedules and can therefore guide issues such as the amount of television viewed. They also have a voice in their children's education and can help ensure day cares follow legislated requirements for quality, daily PA. Second, parents have a direct influence on their children's PA. Their support of PA, their own level of PA, and their enjoyment of PA predict the extent to which their young will engage in PA with sufficient intensity and duration. Far less important, based on this study, is the degree to which parents feel that their children have well-developed abilities when they perform PA.

Results of this study suggest that additional attention should be paid to girls who were found to be less active than their male counterparts. This is certainly consistent with previous research. Similarly, parents may wish to accentuate their support of PA as their children age since it appears that they are less active with each month of development. Whereas being an older parent is a negative correlate of children's PA, marital status, language, educational levels, and household income were not.

As there is evidence that excess weight can track throughout childhood into adulthood [43, 44], public health officials should consider these findings and incorporate appropriate strategies for the prevention of obesity and promotion of PA among young children. Key is the involvement of parents in their children's well-being. As has been made clear in previous research, intervention and prevention efforts beginning early in childhood may also benefit the children's cognitive and socioemotional development in enhancing self-perceived competence and learning through fine and gross motor skills development as well as increasing their social skills through organized sports and physical activities.

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Research Article

Parental Misperception of Their Child's Body Weight Status Impedes the Assessment of the Child's Lifestyle Behaviors

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Objectives. To examine if distinct characteristics are associated with parental misclassification of underweight (UW), normal weight (NW), and overweight or obese (OWOB) children and the implications of misclassification on the parental evaluation of the child's lifestyle habits. *Methods*. Cross-sectional analysis (2004 sample) of the Quebec Longitudinal Study of Child Development (1998–2010) ($n = 1,125$). *Results*. 16%, 55%, and 77% of NW, UW and OWOB children were perceived inaccurately, respectively. Misperception was significantly higher in nonimmigrant parents of UW children, in highly educated parents of NW children and in NW and OWOB children with lower BMI percentiles. Erroneous body weight status identification impedes the evaluation of eating habits of all children as well as physical activity and fitness levels of UW and OWOB children. *Conclusion*. Parental misclassification of the child's body weight status and lifestyle habits constitutes an unfavorable context for healthy body weight management.

1. Introduction

It is well known that not all children have a healthy body weight. In North America, at least 25% of children have above normal body mass index (BMI) [1, 2]. Early interventions and treatments are needed for these children because excess weight during childhood increases the risk of being obese in adulthood and of developing adverse medical conditions [3]. Similar preoccupations also exist for underweight (UW) children. Despite the fact that they represent less than 2% of the children in developed countries, they are a group to care for because of the deleterious effects of this condition on performance, health and survival [4]. To take action, identification of overweight and obese (OWOB) and UW children, as well as key behaviors detrimental to energy balance, is of great importance. Normal weight (NW) children must also be accurately identified, as well as their lifestyle habits, from a primary prevention perspective to avoid excessive weight gain or weight loss.

In clinical settings, less than 20% of health professionals use BMI percentile charts to evaluate the body weight status of children [5]. A review of medical records reveals that only 53% of obese children are identified by clinicians [6]. Nevertheless, it turns out that clinicians are better than parents at classifying a child in the right body weight status group without relying on height and weight measurements: clinicians misclassified about 37% of children compared to about 50% for parents who evaluated their own child [7]. Many studies have documented the specific issue of inaccurate body weight status report by parents. According to these studies, misclassification can reach up to 94%, and in some cases, several factors can influence the accuracy of child body weight status perception by the parent, such as the gender and age of the child, as well as the gender, weight status and education level of the responding parent [7–26]. However, misclassification prevalence and associated factors vary considerably from one study to another, possibly due in part to population specificities. Currently, no study has been conducted in the province of Quebec (Canada), and the only study completed in Canada used a convenient sample from only one city [20]. A limitation potentially even more important is that, despite the growing number of studies in this emerging field of research, it remains unknown if factors associated with the accuracy of parental perception are the same for UW, NW, and OWOB children.

Different misclassification rates and associated factors are reported from one study to another but they all support the presence of deficient screening on the part of both the medical team and the family. This situation can result in a high number of undetected cases, and thus children who have excess or insufficient body weight are left untreated. Better recognition of a child's unhealthy body weight status by the parent is important. Lampard et al. [9] recently showed that lack of recognition of a child's unhealthy body weight by the parent warrants lower concern regarding their weight. Accurate perceptions of eating and exercise behaviors also appear important to ensure optimal body weight control. Scarce information is available on the parental perception of lifestyle habits of UW, NW, and OWOB children. It is known that a majority of mothers of UW, NW, and OWOB children perceives that their child eats not enough, enough and too much, respectively [14, 21]. Also, parents of children above NW do not perceive their child as more physically limited than nonoverweight children [17]. However, the importance of an accurate perception of the body weight status for a good evaluation of the child's lifestyle habits is unknown.

Given the predominant role that parents play in children's health and lifestyle habits, the present study will address the following questions: (1) are factors associated with misperception of the actual body weight status of the child by his caregiver the same among all body weight status groups, and (2) is parental recognition of their child's UW, NW or OWOB status influence the evaluation of eating habits, exercise behaviors and physical capacities of the child?

2. Methods

The Québec Longitudinal Study of Child Development (QLSCD 1998–2010) is conducted by the Institut de la statistique du Québec in collaboration with the Ministère de la Santé et des Services Sociaux du Québec, the Ministère de la Famille et des Aînés du Québec and the Fondation Lucie et André Chagnon. The main objective of this study is to identify and better understand the factors that contribute to social adjustment and the educational achievement of children during early childhood. A sample of children born in the Province of Québec (Canada) in 1998 has been followed since that time, along with their parents. For the purpose of this study, the 2004 sample was chosen because it was the first one with measured fitness variables. Among the 1,529 children evaluated at this time, perceived body weight status by one of their biological parents and measured height and weight were available for 1,131. Normal weight children perceived as bigger than they are (i.e., overweight) were not considered in the analysis due to their small sample size ($n = 6$; <1% of NW children). Analyses were then conducted with a subsample of 1,125 subjects. It is of note that no specific information regarding the purpose of the present study was given to the subjects and their parents. Approval from the Ethics Committee of the Institut de la statistique du Québec and consent from participants were obtained.

2.1. Children Measurements. Trained evaluators weighed children without shoes to the nearest 0.1 kg on a calibrated scale and measured their height with a stadiometer to the nearest 0.1 cm. Weight, height, age, and gender of each child were used to determine BMI percentiles using the 2002 Centers for Disease Control growth chart computer program [27]. The use of these growth charts were recommended for Canadian children as well as the following cutoff points: BMI percentile < 5th: UW; 5th ≤ BMI percentile < 85th: NW; BMI percentile ≥ 85th: OWOB [28]. To document fitness, the following two tests were performed under the supervision of trained evaluators: muscular endurance was assessed by counting the maximum number of sit-ups done in 30 seconds and muscle power was measured as the longest distance achieved after two attempts at the standing long jump.

2.2. Characteristics of the Parents. Parents were considered immigrants if they were born outside Canada and were classified as being either <35 or ≥35 years old on the day of data collection. They were categorized as having a high school diploma or less or a post high school education based on their report at the moment of data collection.

2.3. Parental Perception. The interview questionnaire, available both in French and English, was administered in person to the adult who best knew the child. To assess parental perception of the child's weight status, parents answered the question "In your opinion, compared with other children the same age and for his/her height, would you say that your child..." by "Is thin/slim", "Is of normal weight" or "Is overweight". Children perceived accurately, leaner than they are or bigger than they are, were identified as (=), (−) and (+), respectively. Therefore, the degree of accuracy between measured body weight status and parental perception was coded as follow: UW children perceived "thin/slim": UW(=), UW children perceived as "normal weight" or "overweight": UW(+), NW children perceived as "normal weight": NW(=), NW children perceived as "thin/slim": NW(−), OWOB children perceived as "overweight": OWOB(=), and OW/OB children perceived as "thin/slim" or "normal weight": OWOB(−). Specific questions regarding eating behaviors, physical activity practices and fitness level are presented in Tables 2 and 3.

2.4. Statistical Analysis. Pearson's chi-square tests were used to investigate whether the distribution of categorical variables differs between the groups and to document within each body weight group if the parental perception of eating behaviors differs according to their actual perception of their child's weight status. The same procedure was followed for perception of exercise behaviors and the fitness level of the child, whereas analyses of variance were used for measured

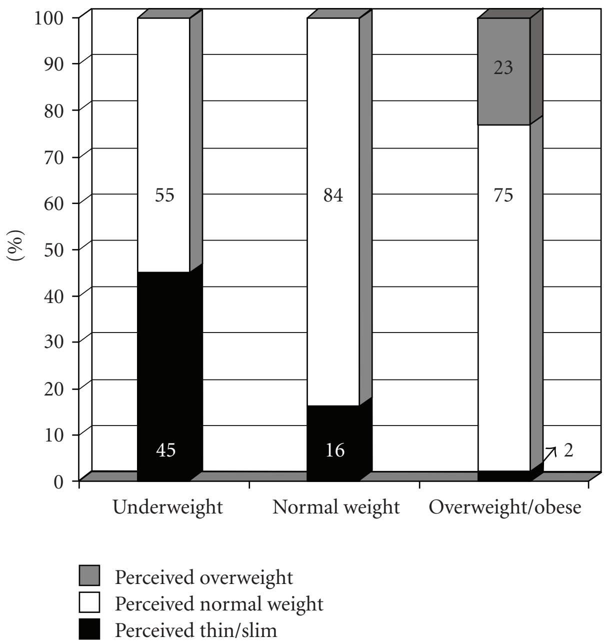

Figure 1: Parental perception of the body weight status of their child per measured body weight categories.

fitness variables. For the purpose of the analyses, answers were grouped when needed so that less than 20% of the categories had a theoretical value below 5, a requirement for using chi-square tests. Differences among the groups for continuous variables were documented with analyses of variance. When significant differences were present in an analysis including more than two groups, Tukey test was used for post hoc comparison. Categorical values presented are *n* (% per body weight group category) and mean score (95% confidence interval) for continuous variables. Statistical analyses were performed with JMP (8.0.2) SAS Institute Inc. and the significance level was set at 0.05.

3. Results

Characteristics of children (gender and age) and responding parents (gender, age, immigration status, and educational level) were similar among UW, NW, and OWOB children (data not presented). Only the BMI in percentile differed significantly between each group: 1.8 (1.4–2.1), 47.2 (45.7–48.8) and 92.7 (92.1–93.4) for UW, NW, and OWOB, respectively ($P < .05$). Figure 1 illustrates the perceived and measured weight status of the child. The accuracy of parental perception differed significantly according to the measured weight status group ($P < .001$): 84% of NW children were perceived accurately compared to only 45% of UW and 23% of OWOB children.

Certain factors were associated with parental misperception in some but not all body weight categories (Table 1). Nonimmigrant parents were more likely to perceive that their UW child is bigger than he or she is. Parents with the highest education level were more likely to report that their NW child is thin/slim [NW(−)]. Also, a child with a lower BMI percentile within the NW or OWOB group was more likely to be perceived as leaner than he or she is. No differences in UW, NW, and OWOB children being perceived accurately were noted based on the gender and age of the child or on the age of the responding parent.

Table 2 presents results pertaining to the impact of parental misclassification of the child's body weight status on perception of eating behaviors. Children are more likely to be perceived as eating enough if they are UW(+) than if they are UW(=), while NW(−) children are more likely to be perceived by their parents as not eating enough than are NW(=) children. NW(−) and OWOB(−) children were reported to overeat less often than NW(=) and OWOB(=) children. The opposite occurs in the UW group, where being perceived as bigger [UW(+)] was related to a larger proportion of children overeating. According to their parents, children refused to eat more often if they were NW(−) than NW(=) and they refused to eat the right food more often if they were OWOB(−) than OWOB(=).

Only one difference was noted regarding the physical activity level of the child as perceived by the parent: OWOB(−) children were, compared to OWOB(=) children, two times more frequently perceived much/moderately more active than comparable children (Table 3). However, objective assessment of various physical activity practices (i.e., days per week) indicated no differences between OWOB(−) and OWOB(=) children. While UW(+) tended to be perceived as less active than UW(=) children, objective assessment of the frequency per week of unorganized sports or physical activities indicates that UW(+) are in fact more active than UW(=) children. No differences were measured between the accurate and inaccurate perception of the physical fitness of UW, NW, and OWOB children. Despite this finding, parents perceived their UW(+) children to be in worse physical fitness than did parents of UW(=) children. OWOB children classified as leaner were more likely to have a better parental evaluation of their fitness.

4. Discussion

Abnormal body weight status in children is a major concern for caregivers. In fact, 78% of parents reported that they would be quite or extremely concerned about their child being overweight [18] and a majority perceived being overweight as linked to future heart problems, limiting playing and exercise practices, and reducing their child's self-esteem [19]. However, parents need to be aware of their child's body weight status to worry about an unfavorable weight status and take action with body weight control [13, 17, 18]. In this regard, the results of the present study confirm what numerous studies reviewed by Towns et al. [11] indicate: parents are bad judges of their children's body weight profile. In the past, factors identified were either investigated only in OWOB children [13] or in a group composed of children of various body weight statuses [7, 8]. The present study was innovative through the identification of factors associated with misclassification specific to the child's actual body weight group: immigration status is important in the UW group, education level in the NW group and BMI percentile

Table 1: Characteristics of the subjects.

	Underweight			Normal weight			Overweight/obese		
	UW(=) ($n = 37$)	UW(+) ($n = 46$)	P value	NW(=) ($n = 711$)	NW(−) ($n = 132$)	P value	OW/OB(=) ($n = 47$)	OW/OB(−) ($n = 155$)	P value
Children									
Gender									
Male	18 (49)	24 (52)	.750	320 (45)	69 (52)	.124	19 (40)	86 (55)	.070
Female	19 (51)	22 (48)		391 (55)	63 (48)		28 (60)	69 (45)	
Age, in years	6.3 (6.2–6.4)	6.2 (6.1–6.3)	.054	6.2 (6.2-6.2)	6.2 (6.2-6.3)	.776	6.3 (6.2–6.4)	6.2 (6.2-6.3)	.383
BMI, in percentile	1.7 (1.2–2.2)	1.9 (1.4–2.4)	.567	49.7 (48.0–51.3)	32.4 (28.6–36.3)	<.001	97.2 (96.3–98.2)	91.4 (90.7–92.0)	<.001
Parent									
Age									
<35 years old	17 (46)	28 (61)	.175	329 (46)	65 (49)	.548	23 (49)	74 (48)	.886
≥35 years old	20 (54)	18 (39)		380 (54)	67 (51)		24 (51)	81 (52)	
Immigrant									
No	24 (65)	39 (85)	.035	548 (77)	103 (79)	.645	32 (68)	111 (72)	.641
Yes	13 (35)	7 (15)		160 (23)	27 (21)		15 (32)	44 (28)	
Highest diploma obtained									
High school or less	8 (22)	17 (37)	.130	242 (34)	33 (25)	.040	21 (45)	60 (39)	.464
Post-secondary	29 (78)	29 (63)		467 (66)	99 (75)		26 (55)	95 (61)	

Results are n (% per body weight category) for categorical and mean score (95% confidence interval) for continuous variables; BMI: body mass index; UW: underweight; NW: normal weight; OW/OB: overweight or obese; (−): perceived leaner than they are; (=): perceived accurately; (+): perceived bigger than they are. Number of subjects per category presented at the top of each column is the maximal number and is accurate for most categorical variables and all continuous variables. For precise number of subjects, calculation of subjects per category can be performed.

in the NW and OWOB groups. In fact, we showed that none of the factors affecting perception of child weight applied to all body weight groups. This study is also the first to demonstrate that parental perception of a child's lifestyle profile differs depending on whether or not the parent is aware of the child's actual body weight status. Moreover, we showed that perceived physical activity level and fitness abilities are discordant with objective assessments for many children. Globally, there is a major impact for a child to be misclassified by his or her parent that goes beyond the weight status identification alone and influences perception of key factors for body weight control.

4.1. Overweight and Obese Children. The case of children with excess body weight deserves special attention considering the high prevalence of OWOB in children and the health implications of this condition. If we take the proportion of unrecognized OWOB children obtained in our study (77%), which is very similar to the 73% obtained by He and Evans [20] in Ontario (Canada) and the 26% of Canadian children aged 6 to 11 who are OWOB [2], we can estimate that one out of five Canadian children in this age group is an unrecognized OWOB child. It should also be acknowledged that misclassification skewed towards a lower body weight status is higher for OWOB children with lower BMI, but a mean BMI percentile of 91.4 for OWOB(−) remains well above the 85th percentile threshold.

Regarding the lifestyle environment and habits, it is currently known that parents of OWOB children are more likely to exert feeding restrictions [29]. However, between 43% [10] and 97% [21] of parents of OWOB children felt that their child either does not overeat or eats right/a little. One limitation of these studies is that they do not discriminate parental perception of eating behaviors based on parents' awareness of their child's body weight status. Only one study indicated that the perception of a child being overweight does not interfere with pressure to eat and restrict eating [25], but the authors did not take into account the actual body weight status of the child. To make up for this shortcoming, we investigated whether an inaccurate perception of OWOB status was associated with lack of recognition of adverse eating habits. We found that parents were significantly less likely to report that their child overeats, and that parents tend to find that the child eats too fast less often when classifying their OWOB child as leaner than he or she actually is. With evidence suggesting that eating fast leads to higher energy intake [30], this finding represents an unfavorable eating context for OWOB(−) children if they are eating fast without the parents noticing. Campbell et al. [14] also report that parents of preschool-aged children express anxiety about thinness and "picky eating" and that overweight children might be perceived as better eaters. In our study, OWOB(−) children were more frequently identified as "sometimes/often refusing to eat the right food" than were OWOB (=) children. If the

Table 2: Comparison of eating habits of children within a given body weight group perceived accurately or not.

	Underweight			Normal weight			Overweight/obese		
	UW(=)	UW(+)	*P* value	NW(=)	NW(−)	*P* value	OW/OB(=)	OW/OB(−)	*P* value
In general, does your child...									
...eat enough?									
Sometimes, rarely or never	15 (41)	5 (11)	.002	79 (11)	44 (33)	<.001	1 (2)	11 (7)	.207
Often	22 (59)	41 (89)		632 (89)	88 (67)		46 (98)	144 (93)	
...overeat?									
Never or rarely	37 (100)	40 (87)	.023	640 (90)	128 (97)	.010	13 (28)	114 (74)	<.001
Sometimes or often	0 (0)	6 (13)		71 (10)	4 (3)		34 (72)	41 (26)	
...eat too fast?									
Never or rarely	29 (78)	37 (80)	.818	559 (79)	99 (75)	.356	25 (53)	106 (67)	.056
Sometimes or often	8 (22)	9 (20)		152 (21)	33 (25)		22 (47)	49 (32)	
...eat between meals so is not hungry at mealtime?									
Never or rarely	16 (43)	26 (57)	.228	442 (62)	77 (58)	.406	34 (72)	104 (67)	.499
Sometimes or often	21 (57)	20 (43)		269 (38)	55 (42)		13 (28)	51 (33)	
...eat at regular hours?									
Never or rarely	1 (3)	1 (2)	.876	4 (1)	2 (2)	.232	1 (2)	1 (1)	.369
Sometimes or often	36 (97)	45 (98)		707 (99)	130 (98)		46 (98)	154 (99)	
...refuse to eat?									
Never or rarely	25 (68)	39 (85)	.064	574 (81)	89 (67)	.001	41 (87)	130 (84)	.575
Sometimes or often	12 (32)	7 (15)		137 (19)	43 (33)		6 (13)	25 (16)	
...refuse to eat the right food?									
Never or rarely	15 (41)	17 (37)	.739	264 (37)	43 (33)	.318	28 (60)	62 (40)	.018
Sometimes or often	22 (59)	29 (63)		447 (63)	89 (67)		19 (40)	93 (60)	

Values are *n* (%) per category of parental perception; UW: underweight; NW: normal weight; OW/OB: overweight or obese; (−): perceived leaner than they are; (=): perceived accurately; (+): perceived bigger than they are.

same reasoning reported by Campbell et al. [14] applies to school-aged children, this evaluation could be potentially problematic for children with a positive energy balance as depicted by a BMI ≥ 85th percentile.

As observed by Eckstein et al. [17], parents of OWOB children do not rate their child as less active or with lower physical abilities than NW children, but those aware of the OWOB status report their child less active than others [17]. This finding suggests that perception of weight status can interfere with the perception of PA and exercise behaviors. To confirm this hypothesis, two sources of information were required and available in the present study: objective questions or measures and subjective questions on physical activity and fitness levels. To this effect, we found that parents who misclassify their OWOB children [OWOB(−)] tend to rate them as more active and in better shape than parents aware of the status of their OWOB children [OWOB(=)]. This conclusion is supported by the findings of Manios et al. [12] which indicate that children seen as leaner, regardless of their actual body weight status, are perceived as more active. However, the present study also indicate that these perceptions are discordant with what parents report as the actual frequency of PA and with what is being measured for fitness. Accordingly, objective measurements or reports of physical activity and fitness levels indicate no differences between the OWOB(−) and OWOB(=) children. Thus, it is legitimate to question if parents would encourage their OWOB(−) child to increase PA and fitness levels if they are not conscious that their child is not as active or in as good shape as they think. This finding also indicates that questions used by professionals regarding exercise and fitness behaviors should avoid comparison with other children and should instead address the actual frequency and physical abilities to provide a good picture of the child's behaviors.

4.2. Underweight Children. The other group that has a potential energy imbalance is UW children. About half of them are perceived as bigger than they are, a result similar to that obtained by Mamum et al. [24] in a larger sample of Australian children. To our knowledge, this study is the first one to address the specific issue of weight status recognition and lifestyle assessment in UW children. In previous studies conducted with more than one body weight group, UW children were either removed because of their low number [17, 20] or grouped with NW children [14]. Assessment of their specific characteristics allowed us to determine that only in this group does one of the parental characteristics differ according to an accurate or an inaccurate evaluation.

Table 3: Comparison of physical activity level and fitness of children within a given body weight group perceived accurately or not.

	Underweight			Normal weight			Overweight/obese		
	UW(=)	UW(+)	P value	NW(=)	NW(−)	P value	OW/OB(=)	OW/OB(−)	P value
In your opinion, how physically active is your child compared to other children the same age and sex?[†]									
Much or moderately more	15 (41)	10 (22)	.064	235 (33)	52 (39)	.161	7 (15)	58 (37)	.004
Equally, moderately or much less	22 (59)	36 (78)		475 (67)	80 (61)		40 (85)	97 (63)	
In the last 12 months, outside of school hours, how often has your child taken part in sports with a coach or instructor (except dance or gymnastics)?[§]									
Most days or a few times a week	4 (11)	7 (15)	.556	108 (15)	18 (14)	.646	9 (19)	23 (15)	.478
About once a week or less	33 (89)	39 (85)		603 (85)	114 (86)		38 (81)	132 (85)	
In the last 12 months, outside of school hours, how often has your child taken lessons or instruction in other organized physical activities with a coach or instructor such as dance, gymnastics, martial arts or circus arts?[§]									
Most days or a few times a week	4 (11)	4 (9)	.746	55 (8)	9 (7)	.715	5 (11)	11 (7)	.431
About once a week or less	33 (89)	42 (91)		656 (92)	123 (93)		42 (89)	144 (93)	
In the last 12 months, outside of school hours, how often has your child taken part in unorganized sports or physical activities without a coach or instructors?[§]									
Most days or a few times a week	19 (51)	34 (74)	.034	478 (67)	81 (61)	.190	27 (57)	99 (64)	.426
About once a week or less	18 (49)	12 (26)		233 (33)	51 (39)		20 (43)	56 (36)	
Compared to other children of your child's age and sex, how do you consider the physical fitness level of your child?[†]									
Much or moderately more	12 (32)	6 (13)	.033	231 (33)	49 (67)	.304	9 (19)	54 (35)	.042
Equally, moderately or much less	25 (68)	40 (87)		479 (67)	83 (63)		38 (81)	101 (65)	
Measured physical fitness[§]									
Sit ups	7.3 (5.6–9.1) $n = 36$	6.4 (5.6–9.1) $n = 44$	.370	7.4 (7.1–7.8) $n = 674$	6.7 (5.7–7.6) $n = 121$	.105	5.2 (3.8–6.5) $n = 45$	6.4 (5.6–7.1) $n = 137$	.128
Long jump	88.7 (80.4–96.9) $n = 35$	87.5 (80.9–94.1) $n = 46$	.823	96.3 (94.5–98.1) $n = 691$	94.6 (89.9–99.2) $n = 125$	.474	84.7 (77.9–91.4) $n = 46$	92.0 (87.8–96.3) $n = 144$	.084

Categorical values are n (% per category of parental perception, i.e., −, = or +); continuous values are mean score (95% confidence interval) UW: underweight; NW: normal weight; OW/OB: overweight or obese; (−): perceived leaner than they are; (=): perceived accurately; (+): perceived bigger than they are. [†]: subjective assessment; [§]: objective assessment.

In fact, no differences were noted in the accurate perception of children based on the immigration status of the parents when all body weight groups were considered together (data not presented). However, while having immigrated to the United States earlier increased the accuracy of body weight recognition in all body weight status groups [22], we found that UW children of parents born inside the country (Canada) were more likely to being perceived as bigger than they are. No explanation is currently available to explain why this difference is present. Maybe that parents born and raised in a country and during a period where leanness is so present in the media landscape and where OWOB is so present in the society could contribute to distort the evaluation of what is a UW child. Studies that use focus groups or interview could considerably help understand why Canadian parents do not recognize the fact that their child is UW. For sure, this subgroup of UW children perceived as bigger is in a situation that can lead to the maintenance of an inadequate energy balance and may thus warrant specific consideration.

Underweight children are the other group along with OWOB children in which perception of both eating and physical activity/fitness are influenced by parental accurate perception of body weight status. When perceived as bigger than they are, UW children are more likely to eat enough and overeat according to their parents. Interestingly, UW(+) children tend to be perceived as less active [22% are identified as much or moderately more physically active compared to other children versus 41% for UW(=); $P = .064$] while they in fact take part in unorganized sports and physical activities more frequently than do UW(=) children. Therefore, children in our study or a mixed sample of children in the one by Manios et al. [12] perceived as leaner were misperceived as more active. In a similar way, UW(=) children are perceived to be in better shape than are UW(+) children, even when direct measurements reveal no difference. Globally, some parents unaware of the UW status of their child perceive that they eat too much despite a potential need for higher energy intake, and they could underestimate their child's energy expenditures versus physical activity. This combination can exacerbate the negative energy balance of these children.

4.3. Normal Weight Children. Eight out of ten NW children are accurately perceived and the remaining ∼20% are most likely to be perceived as leaner than they are. Children were more likely to be in the NW(−) group if their BMI is lower and their responding parent more educated. This latter finding goes against findings obtained in Italy where higher education was associated with better identification among all body weight statuses [10, 22] and in the United States where no differences in education level was present between OWOB children depending on whether or not they were accurately identified [19, 24]. The findings are, however, in line with the fact that more educated people are more inclined to give answers that conform to societal norms [31] and that the desire to be thin/slim is highly prevalent [32]. Therefore, higher social desirability could favor identification of NW children as thin/slim and subgroup analysis in this study could explain some discrepancy with previous publications.

Normal weight children might not be the group for which body weight control concerns are high but they are not protected from a shift in weight status. Genovesis et al. [10] reported that one out of four parents of NW children perceive that his or her child is not eating enough. The present study reveals that NW(−) children, despite their mean 32.4 BMI percentile, may be the ones especially targeted by parents to increase energy intake. In fact, NW(−) children are perceived to eat enough and to overeat less often than are NW(=) children. In addition, they are more likely to refuse to eat, according to their parents. Altogether, these perceptions can favor a parental predisposition to increase food intake in NW(−) children and potentially induce a positive energy balance. This conclusion is further supported by the fact that perception and objective assessments of an important factor of energy expenditure, physical activity, reveals no difference between those NW children perceived accurately or inaccurately.

4.4. Limitations. Given the nature of the present study, there are limitations that need to be acknowledged. The influence of the gender of the respondent (mother or father) could not be studied because fathers were underrepresented as respondents ($n = 18$). This finding is concordant with other studies where fathers represent a low proportion of respondent [17, 19]. Normal weight children perceived as bigger than they are were also removed from the analysis due to their small number. It was also impossible to go beyond the influence of the immigration status and study the impact of the various ethnic groups regarding weight status recognition because of the small number of individuals in each group. The evaluation of eating behaviors was based only on parental perception, while fitness and PA levels were also documented objectively. It should also be recalled that conclusions obtained in this study might not apply to parent-child dyads in all countries or to children from a different age group.

4.5. Research and Intervention Perspectives. The difficulty associated to the accurate perception of eating, physical activity and fitness profile is a challenge for many parents. One cause that might be to considered in the present case is the fact that, on a regular basis, public health messages and publicities reinforce the link between body weight control and lifestyle behaviors (eating and exercise habits). It is possible that parents rely on something that seems easier to assess, that is, body weight status, to evaluated key components of their child energy equilibrium. An interesting area of inquiry would be to document if correcting the child body weight status perception by the parent have an impact on the evaluation of lifestyle behaviors.

Weight status identification is a simple procedure accomplished via anthropometric measurements that may be used to increase body weight status recognition. Interestingly, this awareness is desired by most parents (66%) and accepted by almost all children (96%) [29]. As a matter of fact, knowing their weight status appears to be positive for children's self-esteem, which increases in NW children and remains stable in OWOB children [29]. To increase parental awareness of the child's body weight status, family interventions appear to be necessary given that there is poor agreement between the parental recognition of the weight status of their own children and of unrelated children [22]. Also, once identified, it is essential that children with an unhealthy body weight status as well as their families are guided towards healthy and effective actions. As a matter of fact, recognition of OWOB status does not guarantee a better weight outcome for children. For example, parents of an OWOB child aware of the child's weight status were more inclined to encourage dieting, but the weight outcome in adolescents was less favorable five years later [26]. However, Grimmett et al. [29] showed that informing a family about a child's weight status in combination with providing information on healthy habits better prompts eating and physical activity changes in families. In fact, families with a NW child changed their eating and physical habits in 12% and 10% of the cases, respectively, compared to 49% and 48% in families having an OWOB child, respectively. School-based activities on recognition, evaluation and integration of healthy eating and exercise habits by the child and his family also deserve consideration for future interventions. Currently, no intervention program addresses the specific issue of body weight and lifestyle misperception. The "Healthy Mind and Healthy Body" program that promotes body weight acceptation by teenagers is potentially a good basis to the development of an intervention on bodyweight and lifestyle habits recognition since it uses a very positive approach and is design for administration in schools [33]. School-based programs appear of interest because they are the best place to reach a large number of children with body weight status and lifestyle behaviors not perceived accurately by the parent since these families won't consult for a problem they are not aware of. To target directly teenagers might be a good start for lifestyle and body weight awareness based on extrapolations by Meiser-Stedman et al. [34] made on psychological components [34]. This group showed that parents perceived less psychological impairments such as anxiety in their child following a traumatic event experienced by the child than what the child actually perceived. This raises the issue of the relative importance of body weight and lifestyle behaviors perceptions of the child and parents: does one impact more the future body weight status of the child; on who's perceptions should clinicians pay attention to correct perceptions, child or parent; and does the age of the child matters in the identification of interlocutor? For sure, the use of a multidisciplinary team (ex. nutritionist, kinesiologist and psychologist) and guidance offered to parents [35] are two key components of program designed for children body weight issues that warrant great consideration.

Presently, the potential impact of weight status recognition is less well documented for UW children. Consequently, this lack of data reinforces the importance of developing integrated intervention and supervised programs specifically for different body weight statuses to avoid potential adverse health consequences of body weight recognition and counteract health impairments related to unfavorable body weight status. Moreover, determining the impact of accurate parental lifestyle assessments and interventions that target better recognition of these habits on body weight control of children appears to be a complementary step in this field of research.

5. Conclusion

Parental awareness of their child's body weight status is far from optimal, especially for UW and OWOB children. This study reveals that children and parental characteristics associated with misclassification are specific to the weight status group of the child and that these specific considerations can be used to target a specific group at higher risks of erroneous identification. Numerous differences in eating habits exist between accurately perceived and inaccurately perceived children, and this fact may suggest that parents rely on body weight status perception to appreciate the eating habits of their child. Comparison of parental perceptions and objective measurements of fitness and physical activity levels support the fact that UW and OWOB children are poorly evaluated according to the parental perception of their weight. Consequently, the familial environment of inaccurately perceived children constitutes an unfavorable context for children to adopt and maintain a healthy lifestyle, and thus to improve or maintain their body weight status.

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Research Article

Promoting Moderate-Vigorous Physical Activity in Overweight Minority Girls

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There is limited research on the types of activities that are most effective for promoting MVPA in children. *Purpose*. To assess which types of activities elicit MVPA in overweight minority girls. *Methods*. Sample consisted of 31 overweight (BMI ≥ 85th percentile) Latina and African-American girls (mean age 10.3 ± 1.2 years). Participants wore an Actical accelerometer each day for 8 hours for 15 days to assess engagement in MVPA during their participation in a three-week activity intervention that included traditional fitness, sport skills, games, dancing, and flexibility sessions. *Results*. On average 62% of participants met the MVPA recommended guidelines (60 min/5d/wk) with an average of 68.5 ± 14 minutes of MVPA across the three weeks. Traditional fitness sessions elicited the highest percent of MVPA (mean time spent in MVPA = 32%), followed by dancing and games (mean time spent in MVPA = 21%), sports skills (mean time spent in MVPA = 18%), and flexibility (mean time spent in MVPA = 7%). Step aerobics and rumba fitness elicited the highest proportions of MVPA. *Conclusion*. Traditional fitness activities were identified as the most successful in eliciting MVPA in overweight Latina and African American girls.

1. Introduction

Childhood overweight is a major health problem in the United States. The overweight prevalence defined as >85th age- and gender-specific percentile for body mass index (BMI) in children and adolescents aged 2 to 19 years tripled between 1980 and 2002 [1–3]. A more recent estimate from the 2003-2004 National Health and Nutrition Examination Survey suggests that one out of three children in the United States is overweight [4]. The highest rates of overweight prevalence were reported for Mexican American children and African American girls.

Physical inactivity is deemed a major factor contributing to the energy imbalance that leads to excess adiposity [1]. The US Centers for Disease Control and Prevention (CDC) recommend that children and adolescents engage in 60 minutes of daily moderate to vigorous physical activity (MVPA) five out of seven days to achieve health benefits [5]. MVPA levels vary as a function of gender and age. Evidence indicates that only 42% of boys and 11% of girls meet 60 $\text{min}\cdot\text{d}^{-1}$ of MVPA [6]. Similar results have been reported in other studies [7–9]. Pate et al. [10] estimated the percentages of 1379 children and adolescents (aged 7 to 12 years) that met recommended physical activity guidelines using accelerometry. Results of this study revealed that in elementary school aged children exhibited ≥1 hour of physical activity of at least moderate intensity on five or more days of the week. However, just 34% and 25% of adolescent boys and girls, respectively, met this guideline. Troiano et al. [11], using a national sample, reported that 49% of boys and 35% of girls between the ages 6–11 years engaged in the recommended amount of MVPA. However, by adolescence (aged 12–15 years), a significant decline occurred with only 12% of boys and 3.5% of girls achieving this goal. Similarly, data from the National Health and Nutrition Examination Survey 2003-2004 indicated that 52% of boys and 36% of girls between the ages 6–11 years engaged in the recommended amount of MVPA. In contrast, only 15% and 3% of boys and girls, respectively, engaged in MVPA by ages between 12 and 15 years [12]. Overall, these studies indicate that girls are less likely to achieve the MVPA recommendation than boys and with age there is a severe decrease in the percentage of girls achieving the MVPA recommendation.

After controlling for age and gender, overweight children are likely to have lower levels of physical activity than their nonoverweight counterparts [13, 14]. In a study using a national sample, Whitt-Glover et al. [12] found that approximately 60% of normal weight children (aged 6–11 years) achieved MVPA recommendations compared to 31% of overweight children. Similarly, Deforche et al. [15] observed that compared to normal weight, overweight children had lower levels of physical activity. In a study of adolescents, having normal weight-for-age status was significantly associated with higher bouts of moderate to vigorous physical activity [16]. Trost et al. [17] compared physical activity patterns of 133 nonobese and 54 obese sixth-grade children. They observed that over a seven-day period obese children exhibited significantly lower daily accumulations of MVPA relative to their non-obese counterparts.

Ethnic differences in physical activity levels have also been observed, with Latino and African American children showing lower levels of physical activity than their White counterparts [18–22]. Moreover, among overweight Mexican-American and African-American children only approximately 30% met MVPA guidelines. In a large study of Latino children, Butte et al. [23] observed that overweight adolescent girls had the lowest rates of MVPA. Inactivity in minority children, particularly, among overweight Latina girls, highlights the need to identify which types of physical activities might be effective in promoting the recommended amount of minutes of MVPA among overweight minority girls. Thus, the primary purpose of this exploratory study was to determine which types of physical activity generated greater amounts of MVPA in overweight minority girls. We assessed the contribution of 21 different physical activities (including traditional and nontraditional activities offered in school as well as culturally relevant activities) in eliciting 60 minutes of daily MVPA. These physical activities were grouped into five categories: traditional fitness, dance, games, sports skills, and flexibility. According to the CDC, to achieve MVPA guidelines children and adolescents should engage in aerobic or traditional fitness activities, games, sports skills, and dancing [24]. Based on a compendium of energy expenditure for youth [25], we hypothesized that traditional fitness activities would elicit the highest proportion of minutes of MVPA compared to flexibility sessions, with dance, games, and sport skills falling in the middle. We also tested several types of culturally relevant dances (e.g., rumba fitness, Salsa, and hip hop) since dancing has been identified as effective to increase physical activity in African-American girls [26].

2. Methods

2.1. Participants. Thirty-seven girls (27 Latina and 10 African American) participated in this study. They were part of a larger three-week family-based healthy lifestyle summer intervention titled Behavior Opportunities Uniting Nutrition, Counseling, and Exercise (BOUNCE) [27]. Girls' mean age was 10.8 years (SD = 1.2 years, range from 8 to 14 years). Study inclusion criteria included (1) self-identification of Latino or African-American origin from parents and child; (2) age of child between 8 and 14 years; (3) child classified as overweight (body mass index (BMI) ≥85th to 94th percentile for age) or obese (BMI ≥95th percentile for age); (4) a medical examination acknowledging that the child had no physical impediments that could hinder her participation in this study; (5) child's commitment to attend the entire study. Participants were recruited through flyers and referrals by school counselors, nurses, and teachers. Written informed assent and consent from the child and parents were obtained. The University of Houston Committee for the Protection of Human Subjects granted permission for the study to be conducted and approved all research protocols and consent/assent forms.

2.2. Intervention. As part of the BOUNCE intervention, girls participated in group sessions of exercise, nutrition education, and behavioral counseling for three weeks, 5 days (Monday–Friday) per week, from 9:00 AM to 5:00 PM each day. A detailed description of the nutrition and behavioral counseling components of the BOUNCE intervention are specified elsewhere [26]. For this section, we will focus on the description of the BOUNCE exercise program. As shown in Table 1, the BOUNCE exercise program was composed of 21 diverse group physical activities of varied target intensities (light 2 METs, moderate 3–5 METs, and vigorous 6 METs and above) according to the Ridley et al. [25] compendium. According to their types, physical activities were grouped into *flexibility, sports skills, games, traditional fitness, and dance* categories. We exposed participants to traditionally (e.g., sport skills) and nontraditionally offered physical activities (e.g., yoga, Pilates, ballet, cheerleading, rumba fitness, Salsa, modern and line dance) in school with the aim to engage participants in diverse, novel, and fun ways to be active.

The BOUNCE exercise program was standardized with a typical day beginning with a *flexibility* session (30 minutes) followed by a *sports skills* session (60 or 105 minutes) or *games* session (75 minutes). Lunch and a nutrition lesson were then followed by a *traditional fitness* session (60 minutes). Following a counseling session, the day would end with a *dance* session (60 minutes). Thus, participants engaged in four different physical activities daily. Each BOUNCE exercise session included 5-minute warm-up, light to vigorous physical activity, and 5-minute cool-down phases with an emphasis on continuous movement and minimal standing around in an effort to maintain a safe elevated heart rate. For example, participants were encouraged to move or march in place while listening to instructions or waiting their turn. Also, participants were encouraged to engage in the BOUNCE specific physical activities to the best of their abilities. We recognized that despite our best efforts some BOUNCE sessions (e.g., badminton) generated stationary periods among girls.

Table 1: Weekly offered bounce exercise sessions.

Category	Activity	Target intensity	*Duration (minutes) Week 1	Week 2	Week 3	Total
Flexibility	Yoga/Stretching	Light	30	30	60	120
	Pilates/Stretching		30	30	30	90
	Ballet/Stretching		30	30	30	90
Sports skills	Basketball	Light-moderate	60	0	60	120
	Walking		60	0	0	60
	Soccer		60	60	60	180
	Badminton		0	60	60	120
	Tennis		0	105	0	105
	Self defense		60	60	60	180
Games	Survivor game	Light-moderate	75	0	0	75
	Amazing race		0	75	0	75
Traditional fitness	Step aerobics	Moderate-vigorous	60	60	60	180
	Spinning/circuit		60	60	60	180
	Circuit training		0	60	60	120
	Kickboxing		60	60	0	120
Dancing	Rumba fitness	Light-moderate	60	0	0	60
	Salsa		0	0	60	60
	Hip hop		60	60	60	180
	Cheerleading		60	60	60	180
	Modern dance		0	0	60	60
	Line dancing		0	60	0	60

* Including 5 minutes warm-up and 5 minutes cool-down and instructional times.

Instructors certified by the nationally recognized Cooper Institute led exercise sessions at a gymnasium and dance studio located on a university campus. In addition, 3 exercise science undergraduate students assisted instructors and participants during the exercise sessions. For instance, during the exercise session these students mingled with the participants to encourage them with positive praise, to show them how to perform a movement, and to assist them if they were confused or not feeling well. Instructors and exercise assistants participated in four meetings prior to the BOUNCE program to discuss the standardization of the exercise program.

The BOUNCE exercise program was designed to be enjoyable and appealing by allowing participants to use various pieces of exercise equipment (e.g., colorful jump ropes, resistance bands, and hula hoops) and colead some of the exercise sessions, by using several of the participants' favorite music in the exercise sessions, and by partnering participants with others as "buddies." In addition, we employed other strategies to encourage active participation. First, we asked participants to sign a contract at the beginning of the exercise program by which they agreed to participate in all physical activities. Second, participants received weekly reports of their levels of physical activity achieved in the previous week. Third, prizes were awarded to participants who reached weekly goals. Fourth, participants received handouts on the exercise benefits, components of a healthy lifestyle, and strategies for overcoming barriers to being physically active.

2.3. Measures. Baseline demographic data consisted of questions about age, date and place of birth, and self-described ethnicity. Anthropometric assessments were conducted at baseline and postintervention and included body weight and height measured to the nearest 0.1 kg and 0.1 cm, respectively, using a scale (Tanita TBF 215) and a stadiometer. Height was determined without shoes with the heels of both feet together and the toes pointed slightly outward at approximately a 60-degree angle, arms were at sides, and shoulders were level. Heels, buttocks, and back of the head were touching the vertical backboard and we lowered the headpiece until it firmly touched the crown of the head. BMI was calculated using Quetelet's index (body weight (kilograms)/height^2 (meters)). BMI values were then used to identify the age- and gender-specific percentile for each child using CDC growth charts [28]. Based on these percentiles, each child was classified as overweight (85th–94th percentile for age and gender), or obese (≥95th percentile for age and gender) [28].

Actical accelerometers (Mini Mitter, a Respironics Co., Bend, OR) were used to measure frequency, duration, and intensity of physical activity objectively for 15 days. The Actical is a lightweight accelerometer built from a cantilevered rectangular piezoelectric bimorph plate and seismic mass, which is sensitive to movement in all directions. Actical stores movement information as activity counts. For the proposed study, each participant was shown the placement procedures for the Actical accelerometer at the right hip just above the iliac crest using an elastic strap and plastic buckle to secure the accelerometer around the waist. Participants were instructed to wear the accelerometer daily throughout the BOUNCE intervention (Monday–Friday) from arrival time to the end of the last BOUNCE exercise session. The Actical accelerometer was programmed to collect data from the beginning of the first exercise session at 9:00 AM until the end of the last exercise session at 5:00 PM. The accelerometers were set to record in 60-second epochs. Each day a research assistant logged the start and end times of each physical activity session and recorded the participant's attendance.

Upon completion of each five-day intervention week, accelerometer data (activity counts per minute) were downloaded into the Actical program and exported to an Excel spreadsheet for initial analysis. In the initial examination, data completeness was verified against an exercise log and attendance roster. After this initial data screening, activity counts were summed for each day and each activity. Activity counts per minute were partitioned as moderate-vigorous (MVPA: $\geq$1500 counts$\cdot$min^{-1}), light (LPA: >100–<1500 c$\cdot$m^{-1}), and sedentary activity (SA: $\leq$100 c$\cdot$m^{-1}) intensities using cutoff points developed by Puyau et al. [29]. The number of daily minutes spent at each intensity level was calculated by averaging the number of minutes spent at each intensity level (e.g., SA, LPA, and MVPA) across all participants for each day. The proportion of total activity time spent in MVPA (number of minutes at or above 1500 counts per minute divided by total time in each activity) was calculated for each of the 21 physical activity sessions. The MVPA achieved during these physical activity sessions was grouped into one of five general activity categories: flexibility, sports skills, games, traditional fitness, and dancing.

2.4. Statistical Analysis. Descriptive statistics (e.g., means, standard deviations, ranges) were calculated for all variables. The primary study variables included the average number of daily minutes spent in MVPA as well as LPA and SA. Repeated measures ANOVA with repeated contrasts was employed to determine changes in the average daily minutes of MVPA with each successive week of the program (i.e., week 1 to week 2 and week 2 to week 3) and to determine if the percent time spent in MVPA differed significantly among the activity categories. Alpha was set at 0.05. All statistical analyses were conducted using SPSS statistical package, version 15.0.

3. Results

3.1. Sample Characteristics. Of the 37 participants, data from six participants were excluded from the analysis because they did not have at least 12 days of accelerometer data reducing the final sample to 31. No significant differences were found between those who completed at least 12 days of accelerometer data and those who did not. Twenty-three percent of the participants were classified as overweight and 77% were classified as obese with a mean ($\pm$SD) BMI of 29.2 $\pm$ 6.6. The mean number of days that accelerometers were worn by each participant was 13.8 $\pm$ 1.1 days. Over half of the girls (59%) came from low-income families as evidenced by receiving federally funded free school meal assistance.

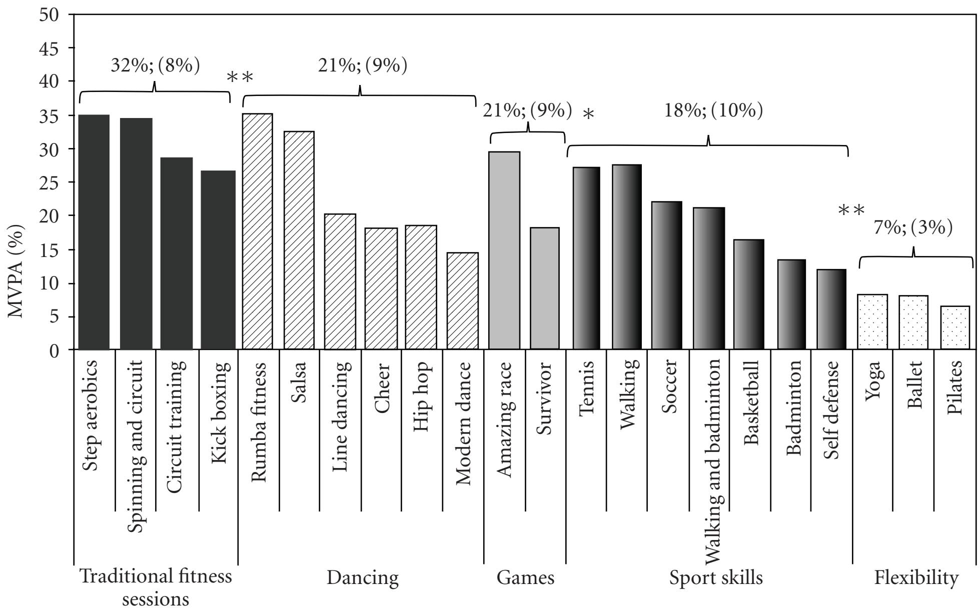
3.2. Time (Minutes) Spent in MVPA. Girls' average time spent in MVPA improved each week (week 1 = 60.47 minutes $\pm$ 16.70 minutes, week 2 = 70.32 minutes $\pm$ 19.51 minutes, week 3 = 74.70 minutes $\pm$ 15.67 minutes). These improvements were statistically significant ($P < .01$) both from week 1 to week 2, and from week 2 to week 3 with an average of 68.5 $\pm$ 14 minutes of MVPA across the three weeks of the study. Fifty-six percent of girls met MVPA guidelines during week 1, 66% of girls during week 2 and 63% during week 3 with an average of 62% of the girls meeting MVPA guidelines from 9:00 AM–5:00 PM period when accelerometers were worn.

3.3. Proportion of Time Spent in MVPA during Specific Physical Activities. Participants' percentage of time spent in MVPA across each of the different 21 physical activity sessions is presented in Figure 1. The percentage of time spent in MVPA ranged from 6% (Pilates) to 35% (step aerobics and rumba fitness). The average percentage of time spent in MVPA across the five general activity categories (*traditional fitness, dance, sports skills, games, and flexibility*) is also presented. Overall, traditional fitness sessions elicited the highest percent MVPA (mean = 32 $\pm$ 8%), followed by dancing and games (mean = 21 $\pm$ 9%), sports skills (mean = 18 $\pm$ 10%), and flexibility (mean = 7 $\pm$ 3%).

A statistical analysis comparing MVPA across the five activity categories indicated that traditional fitness sessions yielded significantly more MVPA than dancing and games sessions ($P < .01$). The amount of MVPA generated by dancing and games was not significantly different ($P = .66$). However, dancing and games sessions elicited significantly more MVPA than sports skills sessions ($P = .03$), and sports skills sessions elicited significantly more MPVA than flexibility sessions ($P < .01$).

4. Discussion

The primary purpose of this exploratory study was to determine which types of physical activities generated the highest proportion of MVPA in overweight minority girls. Findings indicate that traditional fitness activities were the most effective in yielding the highest proportion of MVPA in overweight minority girls while flexibility activities were the least effective with sports skills, dance, and games falling in the middle. An examination of specific physical activities revealed that step aerobics and rumba fitness elicited the highest proportions of MVPA followed by spinning/circuit training and Salsa. In contrast, Pilates sessions elicited the least proportion of MVPA. Thus, these results suggest that it is advisable to offer a variety of traditional fitness activities as well as some culturally appropriate activities such as rumba fitness to elicit MVPA in overweight Latina and African-American girls.



*$P < .05$
**$P < .01$

Figure 1: Mean and standard deviations of percentage of time spent in MVPA.

Based on objective measurements of physical activity, it was observed that on average, 62% of participants met MVPA recommended 60 $\min \cdot d^{-1}$ guidelines and spent an average of 68.5 ± 14 minutes in MVPA during the 9:00 AM–5:00 PM period when accelerometers were worn. Compared with the previous studies attempting to promote physical activity in minority girls [25, 30–32], our findings are quite noteworthy. In this study, the overweight girls participated in 210–225 minutes of daily physical activity (including approximately 40 minutes of warm-up and cool-down time). Given the fact that not all girls achieved the 60 minutes of MVPA, improvement is needed in motivating overweight girls to increase their PA intensity during the day. This fact not only highlights the need to develop interventions that include effective types of physical activities to achieve MVPA guidelines, but also to train instructors in motivational techniques.

To our knowledge, this is one of the few studies conducted with Latina and African-American girls which assessed MVPA objectively during 15 days of intermittent and sustained physical activity, matched with a valid record of physical activities offered during the intervention. The majority of research to date has focused on total daily minutes of physical activity in a free-living environment and has relied on self-report activity logs [33]. Some limitations of this exploratory study are noted including the small sample size and homogeneity of the sample (overweight and low-income minority girls) which limit the generalizability of the results to the general population of Latina and African-American girls of varied weight and socioeconomic status. Another limitation of this study is the lack of inclusion of psychosocial measures in order to assess participants' enjoyment, motivation, perceived competence, and/or self-efficacy for the activities involved. It would make a contribution to the literature to know if girls engage in more MVPA minutes in activities they claim to enjoy more. For instance, since we did not measure motivation, we could not address whether the highest proportion of MVPA generated by rumba fitness was due to the type of dance movements or due to the greater motivation of the girls or both. Despite the limitations this exploratory study provides valuable information regarding the most effective types of activities in eliciting MVPA in overweight Latina and African-American girls. Such information will guide researchers, physical education teachers, and health educators in designing more effective and culturally appropriate interventions intended to increase the daily amount of MVPA in high risk populations of overweight Latina and African-American girls.

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Research Article

Children's Use of Electronic Games: Choices of Game Mode and Challenge Levels

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Introduction. Interactive electronic games are popular and are believed to contribute to physical activity accrual. The purpose of this study was to examine children's electronic game use during conditions in which they had free access to selecting interactive and seated screen-based versions of electronic games and during the interactive versions had free choice in making adjustments to the activity intensity. *Methods*. We systematically observed 60 Hong Kong primary school children during two 60-minute game sessions while simultaneously recording their game mode choices and physical activity levels using SOFIT (System for Observing Fitness Instruction Time). *Results*. When given free choice, children spent more than half of their available time participating in interactive versions of games. These versions of games provided significantly more moderate-to-vigorous physical activity and greater energy expenditure than the computer screen versions. Children with the opportunity to modify intensity levels spent more time playing the interactive versions and accrued more physical activity. *Conclusions*. The tenets of behavioral choice theory were supported. Access to new-generation interactive games, particularly those with modifiable intensity levels, may facilitate children's participation in physical activity.

1. Introduction

Current health guidelines recommended that children should participate in 60 minutes of moderate-to-vigorous physical activity (MVPA) daily [1]. Children, however, often adopt sedentary lifestyles and there is widespread concern that screen-based media such as computer and video games contribute to sedentary living and childhood obesity problems [2, 3]. New generation interactive electronic games, known as exergaming, have been developed and are considered as a promising way to promote physical activity in children. Previous studies have demonstrated that interactive electronic games can significantly increase physical activity in children [4–6], including eliciting greater energy expenditure compared to seated electronic games [7–12]. Boys are typically found to spend more energy during interactive games than girls [6, 7], but sometimes no significant gender effects are reported [8, 10]. Compared to overweight children, nonoverweight children have been shown to be more willing to play an interactive dance game [13]. These studies, however, have typically assessed children's physical activity levels during short-time periods (e.g., 15 minutes per game segment), and without participants having a choice of the interactive or more sedentary computer screen-based versions of the same game.

Direct observation exceeds other measures of physical activity in providing contextually-rich data on the environment [14, 15]. Several studies have used this method with cohorts of children in their homes in Hong Kong [16] and the USA [17, 18] and have shown that children spend most of their leisure time indoors and in sedentary pursuits. Using the behavioral choice theory [19–21] as a conceptual framework, Sit et al. [22] recently used direct observation to study electronic game behavior during extended time periods (i.e., 60 minutes continuously) and under conditions when children had choices in playing interactive or computer screen versions of the same games—bowling and running. Findings showed that children spent about half their time on the interactive versions of games and that these versions engaged children in substantially MVPA more than during computer screen versions (i.e., 70% versus 2% of game time). Additionally, boys and nonoverweight children expended more energy during the interactive games than girls and overweight children, respectively. The study concluded that children, when given the opportunity (i.e., availability and accessibility), tended to select interactive games over the more sedentary versions of the same sport game.

Reducing sedentary behavior, in particular that associated with screen-time media, continues to be an important goal in childhood obesity prevention and treatment. The present investigation extended the previous study [22] to examine children's electronic game behavior under more complex conditions. Thus, in addition to being able to select sedentary or physically active versions of the same sport games, children were given immediate access to adjusting the levels of challenge (i.e., activity intensity) during the interactive game modes. We hypothesized that giving access to adjusting levels of challenge within interactive games would increase both children's time playing the games and their physical activity levels over the seated versions of the same sport game. We also predicted that boys would spend more time and expend more energy during interactive games than girls.

2. Methods

2.1. Participants. Sixty healthy primary children (35 boys, 25 girls) aged between 9 and 12 ($M = 10.77 \pm 0.79$) were recruited from local primary schools. Informed written consent from children and assent from parents were obtained prior to commencement of the study. Ethical approval was granted by the University of Hong Kong.

2.2. Design and Procedures. The children participated alone in two 60-minute sessions in a controlled laboratory setting. They were allowed to choose and play either an interactive electronic game or a similarly themed computer screen game. They were also allowed to switch between game modes and to stop playing at any time. During session one, the children could select between bowling-type games (i.e., interactive bowling called XAviX Bowling) and. during session two, select between running-type games (i.e., interactive running game called Aerostep), both developed by Shiseido Co., Japan (http://www.xavix.com/). Additionally, the children were randomized by computer into two groups, stratified by gender. One group (i.e., "fixed intensity") played the interactive games in a preset mode while children in the second group (i.e., "adjustable intensity") were permitted to freely modify game difficulty (i.e., intensity) levels. Prior to the study none of the children had previously played either the interactive or computer screen versions of games. All sessions were video-taped for reliability checks and data analyses.

The children were familiarized with the laboratory, the procedures, and the interactive and computer-based versions of the games prior to the game sessions. Anthropometric data were measured using standard practice by a certified technician. Weight was measured to the nearest 0.1 kg and height to the nearest 0.1 cm using a freestanding Seca stadiometer (Seca AG, Reinach, Switzerland). Bioimpedance (TBF-401, Tanita Co., Japan), after controlling for hydration and skin temperature in the air-conditioned laboratory, was used to estimate fat mass (kg), fat free mass (kg), and percent body fat.

2.3. Observation System. A modification of the System for Observing Fitness Instruction Time (SOFIT) instrument [23] was used to determine each child's physical activity and the amount of time he/she spent in each game mode during each of the two 60-min sessions. Physical activity was recorded using momentary time sampling by entering one of five codes every 20 seconds: lying down (code 1), sitting (code 2), standing (code 3), walking (code 4), or vigorous (code 5). These codes have been validated using heart rate monitoring and accelerometry [24–26]. Assessors were trained to use SOFIT following the standard protocol [14], which included memorizing coding definitions and conventions, viewing video segments, and surpassing the interobserver agreement (IOA) of 85% on video assessments prior to data collection. Reliability assessments were performed for 20% of the total data, and IOA for child physical activity levels exceeded 99%.

2.4. Data Analysis. Dependent variables were mean minutes children spent in each game mode, time spent in different physical activity levels, and estimated energy scores. Child physical activity variables were expressed as both minutes per session and as the proportion of session time. The Walking and Vigorous categories were summed to form Moderate to Vigorous Physical Activity (MVPA), a description often used in health-related literature, and when converted to percentage of time serves as a measure of physical activity intensity. In addition, a summary score for estimated energy expenditure during sessions and game modes, Total Energy Expenditure (TEE) (kcal/kg), was obtained using standard calculations based on heart rate monitoring [14]. Independent variables were gender and the interactive game level groupings (fixed, adjustable).

Data were analyzed using SPSS 16.0, and descriptive statistics, including means, standard deviations, frequencies, and percentages, were obtained for all variables. One-way ANOVAs were conducted to test for significant group and gender differences for game modes (i.e., mean minutes for each game mode) and physical activity variables (i.e., the five codes, plus MVPA%, and TEE). Partial Eta Squared ($n_p{}^2$) statistics were used to indicate the relative magnitude of the differences between group means: small = 0.01, medium = 0.06, and large = 0.14 [27]. Chi-square analysis was performed to identify the frequency distribution of group and gender by body weight classification based on Cole et al.'s [28] work. Data checks were performed prior to data analyses to ensure no violation of the assumptions of normality, linearity, homogeneity of variances, homogeneity of regression slopes, and reliable measurement of the covariate. Alpha level was set at $P < .05$ for all statistical tests.

3. Results

3.1. Physical Characteristics of Participants by Group and Gender. Table 1 shows that the adjustable intensity level group and boys had significantly greater body weight, BMI, and BMI *z* score than the fixed intensity level group and girls, respectively. Based on the International Obesity Task Force (IOTF) definitions of child obesity [28], 22 participants were overweight (18 boys, 4 girls) and 9 were obese (8 boys, 1 girl). Results of chi-square statistics (data not shown) indicated that a significantly greater proportion of adjustable intensity level group was overweight or obese than control group, $N = 60$, $\chi = 5.41$, $P \leq .05$. More boys were found to be overweight or obese than girls, $N = 60$, $\chi = 17.21$, $P \leq .0001$. Because BMI was a confounding variable, one-way between-groups ANCOVAs, adjusting for BMI, were performed for subsequent analyses.

3.2. Time Spent during Game Sessions. Children spent nearly all of their allocated 60-minute sessions playing the available games (bowling games, 95.5% of the time; running games, 94.5% of the time). Overall, the children spent the largest amount of time playing the interactive bowling game, followed by the interactive running game, computer screen running game, and computer screen bowling game. Figure 1 shows the mean minutes spent in each game mode by group and gender, after adjusting for BMI. Compared to the fixed intensity level interactive game group, the adjustable intensity level group spent significantly more time in interactive bowling (i.e., 7.8 minutes), $F(1, 57) = 6.70$, $P = .01$, $n_p^2 = .011$; and interactive running games (i.e., 3 minutes), $F(1, 57) = 5.34$, $P \leq .05$, $n_p^2 = .09$; but less time in computer screen bowling, $F(1, 57) = 6.31$, $P \leq .05$, $n_p^2 = .11$. No significant gender differences in the four game modes were noted.

3.3. Levels of Physical Activity during Game Sessions. Table 2 presents the mean minutes and proportion of time children spent in the five activity codes during each game mode. In general, when playing computer screen games, children spent over 95% of their time sitting. In contrast, they spent 77% of their time (25.1 minutes) walking during interactive bowling and 83.8% (25.1 minutes) of their time in vigorous activities during interactive running games.

Results (data not shown here) indicated that the adjustable intensity level group was more physically active than the fixed level group, spending more time walking, $F(1, 57) = 10.47$, $P \leq .05$, $n_p^2 = .16$; and less time standing, $F(1, 57) = 15.32$, $P \leq .0001$, $n_p^2 = .21$; during interactive bowling. The adjustable level group also spent less time sitting during computer screen bowling, $F(1, 57) = 7.23$, $P \leq .05$, $n_p^2 = .11$; and computer screen running games, $F(1, 57) = 4.55$, $P \leq .05$, $n_p^2 = .07$. Compared to girls, boys spent more time in vigorous activities during interactive bowling, $F(1, 57) = 6.78$, $P \leq .05$, $n_p^2 = .11$; and interactive running games, $F(1, 57) = 3.69$, $P \leq .05$, $n_p^2 = .06$. Girls, conversely, spent more time standing, $F(1, 57) = 6.74$, $P \leq .05$, $n_p^2 = .11$; and walking, $F(1, 57) = 3.94$, $P \leq .05$, $n_p^2 = .07$; during interactive running games.

Table 3 presents summary scores for children's physical activity levels during game modes in terms of MVPA percent and TEE. Overall, MVPA percent and TEE were substantially higher during interactive games than their computer screen versions, with the interactive running game producing the highest values.

Compared to the fixed intensity level group, the adjustable level group had greater MVPA percent during interactive bowling, $F(1, 57) = 9.33$, $P \leq .05$, $n_p^2 = .14$; computer screen bowling, $F(1, 57) = 6.32$, $P \leq .05$, $n_p^2 = .10$; and computer screen running games, $F(1, 57) = 5.10$, $P \leq .05$, $n_p^2 = .08$. Similarly the adjustable intensity level group also had higher TEE during interactive bowling, $F(1, 57) = 9.78$, $P \leq .05$, $n_p^2 = .15$; and during interactive running games, $F(1, 57) = 5.31$, $P \leq .05$, $n_p^2 = .09$; but lower TEE during computer screen bowling, $F(1, 57) = 5.90$, $P \leq .05$, $n_p^2 = .09$. No significant gender differences in activity variables were evidenced.

4. Discussion

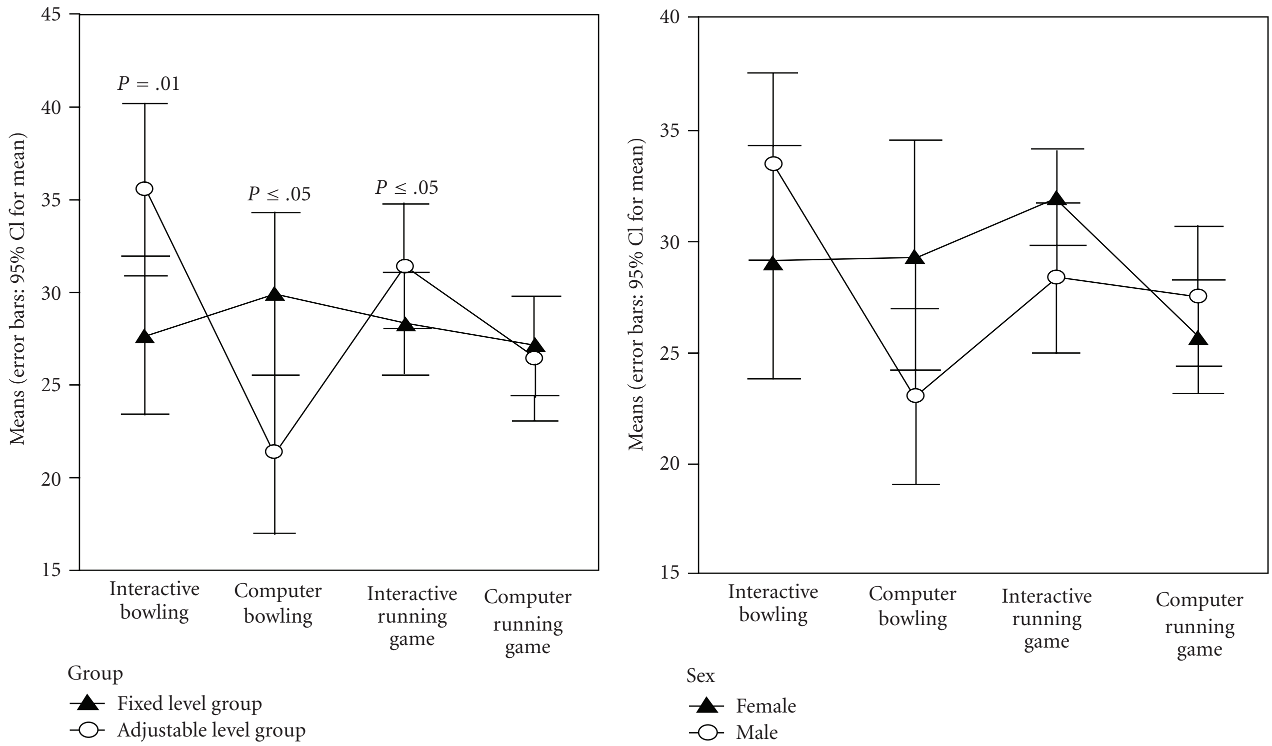
A main aim of the present study was to determine whether access to adjusting difficulty levels (intensity) influences the amount of time and the activity levels in children playing interactive versions of the games. Consistent with an earlier study by Sit et al. [22], when given free choice, children spent about 95% of each allocated hour session playing games. During sessions, they chose to spend over half their time playing interactive games over more sedentary, computer screen versions. The children were substantially more physically active during interactive (88% MVPA) than computer screen (4% MVPA) versions of games, and this is congruent with previous studies which illustrated exergaming can contribute substantially to children's physical activity levels [4–12].

Children in the adjustable intensity level group, who had free access to modifying levels of challenge/intensity in interactive games, spent more time playing the interactive versions of games (bowling, 7.8 more min; running games, 3 more min) than those in the fixed intensity level group. Additionally, they had a higher MVPA percent during interactive bowling and greater TEE during both interactive bowling and running games. These results support the notion that children are attracted by a feature of exergaming that challenges them to engage in physically active behavior while simultaneously decreasing their sedentary computer screen-time behavior [6]. The results also support the tenets of behavioral choice theory, given that the availability of exergaming offered an appealing alternative to sedentary computer screen-based media and that immediate access to different physically active alternatives (i.e., game level adjustments) acted as reinforcers to sustain interactive game play. Previous intervention studies have reported that interactive electronic games are able to motivate children to be more physically active over time [29, 30].

Table 1: Physical characteristics of participants (Mean ± SD).

Variable	All	Interactive game group		Gender	
	$N = 60$	Fixed $n = 30$	Adjustable $n = 30$	Boys $n = 35$	Girls $n = 25$
Age	10.8 ± 0.8	10.9 ± 0.9	10.6 ± 0.6	10.7 ± 0.7	10.8 ± 0.9
Height (cm)	146.3 ± 8.1	145.8 ± 8.3	146.7 ± 8.0	146.0 ± 8.7	146.6 ± 7.4
Weight (kg)	44.4 ± 12.4	41.0±11.7[a]	47.7 ± 12.3[a]	48.2±13.1[a]	39.0 ± 9.1[a]
BMI (kg/m^2)	20.5 ± 4.5	19.0 ± 4.1[b]	22.0 ± 4.4[b]	22.3 ± 4.4[c]	18.0 ± 3.3[c]
zBMI (kg/m^2)	0.0 ± 1.0	−0.2 ± 1.0[b]	0.5 ± 1.0[b]	0.6 ± 1.0[c]	−0.4 ± 0.8[c]

BMI:Body Mass Index.
Significant mean differences between independent variable categories:
$^aP \leq .05$, $^bP \leq .001$, $^cP \leq .0001$.



(a) (b)

Figure 1: Mean minutes spent by game type and mode, after adjusting for BMI.

Contrary to previous studies [6, 7], we found no significant gender differences in the overall amount of time spent in each of the game modes or in MVPA percent and TEE. Boys, however, engaged in a greater proportion of time in vigorous activities during interactive games. In particular, boys spent 85.8% (versus 81% for girls) of their time in engaging vigorous activities during interactive running. This suggests that the physically demanding nature of interactive running game may be more attractive to boys than girls. A confounding event, however, is that the interactive running game required children to mimic "Jackie Chan" (a famous Hong Kong male marital artist) and to engage in a 5-minutes workout continuously. Male combatants would appear periodically and children could make them disappear by quickly stepping on places on a mat. The male characters in the game content might be more attractive to boys, which might, in turn, reinforce and motivate them to exert more effort [31]. Nonetheless, and inconsistent with our previous study [22], game mode selection and activity patterns were similar for boys and girls, suggesting that the availability and accessibility of game level adjustments have a generalizable effect on influencing children's electronic game behavior.

Overall, the current study provides additional evidence to suggest that making interactive games available may reduce the amount of time children spend in sedentary pursuits [19–21]. Built-in challenges based on increased complexity and intensity levels have the potential for engaging children in interactive games for longer periods of time and at higher activity levels. A definite strength of most interactive games

Table 2: Mean proportion of session time ± SD (and mean min ±SD) for activity levels during game type and mode.

Activity	Interactive bowling mean min = 31.6 ± 12.5	Computer bowling mean min = 25.7 ± 12.3	Interactive running game mean min = 29.9 ± 8.3	Computer running game mean min = 26.8 ± 8.0
Lying Down %	0.0 ± 0	0.0 ± 0	0.0 ± 0	0.0 ± 0
	(0.0 ± 0)	(0.0 ± 0)	(0.0 ± 0)	(0.0 ± 0)
Sitting %	5.4 ± 6.4	95.7 ± 4.1	0.9 ± 2.3	95.3 ± 6.0
	(2.0 ± 2.5)	(24.9 ± 12.4)[a]	(0.3 ± 0.6)	(25.7 ± 8.2)[a]
Standing %	16.6 ± 23.9	0.6 ± 1.5	0.7 ± 1.4	0.4 ± 0.8
	(4.2 ± 7.0)[b]	(0.1 ± 0.2)	(0.2 ± 0.4)[c]	(0.1 ± 0.2)
Walking %	77.0 ± 22.6	3.7 ± 3.3	14.6 ± 7.8	3.4 ± 2.8
	(25.1 ± 13.3)[a]	(0.7 ± 0.6)[a]	(4.3 ± 2.7)[c]	(0.8 ± 0.6)
Vigorous %	1.0 ± 2.7	0.0 ± 0	83.8 ± 8.5	0.9 ± 4.3
	(0.3 ± 0.8)[c]	(0.0 ± 0)	(25.1 ± 7.6)[c]	(0.2 ± 0.9)

Significant group difference after adjusting for BMI: [a]$P \leq .05$, [b]$P \leq .0001$,
Significant gender difference after adjusting for BMI: [c]$P \leq .05$.

Table 3: Children's overall mean MVPA%± SD (actual min ± SD) and TEE by game type and mode.

Physical activity levels	Interactive bowling	Computer bowling	Interactive running game	Computer running game
MVPA % (min)				
All	78.0 ± 22.8	3.7 ± 3.3	98.4 ± 2.6	4.3 ± 5.6
	(25.4 ± 13.4)	(0.7 ± 0.6)	(29.4 ± 8.3)	(1.0 ± 1.1)
Group				
Fixed level	(69.0 ± 28.0)[a]	(2.7 ± 2.5)[a]	98.2 ± 2.4	(2.6 ± 2.6)[a]
	(19.3 ± 12.2)	(0.6 ± 0.4)	(26.9 ± 7.2)	(0.6 ± 0.5)
Adjustable level	(87.0 ± 11.4)[a]	(4.7 ± 3.7)[a]	98.4 ± 2.7	(6.0 ± 7.2)[a]
	(31.4 ± 12.1)	(0.8 ± 0.7)	(31.9 ± 9.2)	(1.3 ± 1.4)
Gender				
Boys	82.1 ± 20.9	3.9 ± 3.5	98.5 ± 3.0	4.3 ± 6.1
	(28.3 ± 13.1)	(0.7 ± 0.6)	(28.6 ± 9.7)	(1.0 ± 1.0)
Girls	72.3 ± 24.9	3.3 ± 3.1	98.2 ± 1.9	4.3 ± 4.9
	(21.4 ± 13.1)	(0.7 ± 0.5)	(30.6 ± 5.3)	(1.0 ± 1.2)
TEE				
All	2.76 ± 1.2	1.24 ± 0.6	4.05 ± 1.1	1.32 ± 0.4
Group				
Fixed level	2.28 ± 1.1[a]	1.43 ± 0.5[a]	3.71 ± 1.0[a]	1.31 ± 0.3
Adjustable level	3.24 ± 1.2[a]	1.06 ± 0.5[a]	4.39 ± 1.3[a]	1.32 ± 0.4
Gender				
Boys	3.01 ± 1.2	1.13 ± 0.5	3.97 ± 1.4	1.35 ± 0.4
Girls	2.42 ± 1.2	1.39 ± 0.6	4.17 ± 0.7	1.27 ± 0.3

MVPA:Moderate to Vigorous Physical Activity (walking + vigorous).
TEE:Total Energy Expenditure ($kcal \cdot kg^{-1}$).
Significant group mean difference after adjusting for BMI: [a]$P \leq .05$.

is their ability to be customized in a way to challenge individuals. Because children spend large amounts of time at home and are typically sedentary when observed there [16–18], interactive games have potential to provide opportunities for increasing physical activity in that location.

Limitations of the study include a small sample size, assessing children's physical activity in a controlled setting. and examining only two paired interactive and computer screen electronic games. Future research should focus on larger sample sizes, using additional objective measures of physical activity, and assessing the longer-term outcomes of interactive games interventions on children's physical activity.

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Research Article

Blood Glucose Levels and Performance in a Sports Camp for Adolescents with Type 1 Diabetes Mellitus: A Field Study

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Background. Acute hypo- and hyperglycemia causes cognitive and psychomotor impairment in individuals with type 1 diabetes mellitus (T1DM) that may affect sports performance. *Objective*. To quantify the effect of concurrent and antecedent blood glucose concentrations on sports skills and cognitive performance in youth with T1DM attending a sports camp. *Design/Methods*. 28 youth (ages 6–17 years) attending a sports camp carried out multiple skill-based tests (tennis, basketball, or soccer skills) with glucose monitoring over 4 days. Glucose levels at the time of testing were categorized as (a) hypoglycemic (<3.6 mM); (b) within an acceptable glycemic range (3.6–13.9 mM); or (c) hyperglycemic (>13.9 mM). *Results*. Overall, sports performance skill was ∼20% lower when glucose concentrations were hypoglycemic compared to either acceptable or hyperglycemic at the time of skill testing ($P < .05$). During Stroop testing, "reading" and "color recognition" also degraded during hypoglycemia, while "interference" scores improved ($P < .05$). Nocturnal hypoglycemia was present in 66% of subjects, lasting an average of 84 minutes, but this did not affect sports skill performance the following day. *Conclusions*. Mild hypoglycemia markedly reduces sports skill performance and cognition in young athletes with T1DM.

1. Introduction

Youth with type 1 diabetes mellitus (T1DM) are regularly subjected to periods of both low (hypoglycemia) and high (hyperglycemia) blood glucose levels, as exogenous insulin therapy does not perfectly mimic endogenous insulin needs. The balance of glucose control is particularly challenging in young people with the disease since insulin requirements are influenced by a number of ever changing variables including nutritional intake, physical activity levels, and the circadian rhythms of other anti-insulin hormones. Moreover, any physical or emotional stress, sometimes associated with the stress of competition can increase glycemic excursions [1]. Indeed, the period of adolescence, perhaps because of both physiologic and behavioral factors, make the achievement of optimal glycemic control particularly challenging for youth with T1DM [2]. Regular physical activity (i.e., exercise), while overall has several beneficial effects for the child with T1DM, can make glycemic control very challenging [3]. Immediately following exercise, blood glucose concentrations may be low due to excessive insulin administration or may be high due to the effect of epinephrine release from the excitement and intensity of the exercise. A few hours later, the glucose levels typically fall because of elevated insulin sensitivity that helps replete glycogen stores. Unfortunately, the symptoms of low or high glucose levels are often masked by increased physical activity and sporting competition [4].

Early symptoms of hypoglycemia may include trembling (shakiness), an accelerated heart rate, sweating, and increased hunger. Unfortunately, these early warning symptoms are not always present in a person with diabetes who suffers from autonomic nerve dysregulation. Moreover, evidence suggests that even after a small number of repeated hypoglycemic events, or following prior bouts of exercise, the autonomic response to hypoglycemia is diminished in otherwise healthy persons with T1DM [5]. Symptoms of severe neuroglycopenia generally occur only when blood glucose levels are extremely low (<2.5 mM) or prolonged and can result in acute confusion, disorientation, and clumsiness [6], a situation that is very undesirable from a health and safety perspective. Symptoms of hyperglycemia, on the other hand, may cause fatigue, dehydration and blurred vision or may go completely unnoticed by the individual [7]. What is particularly challenging in recognizing hypo- and hyperglycemia in active adolescents with T1DM is that many of the symptoms are also associated with vigorous exercise (increased heart rate, sweating, shakiness, fatigue, dehydration, etc.), thus making increased glucose monitoring critical [3].

The degree to which acute or chronic hypoglycemia or hyperglycemia influence sports performance is unclear. Circumstantial evidence suggests that an increase in plasma glucose availability might improve the exercise capacity perhaps because more fuel is readily available for muscle contraction. Some performance-related studies document an ergogenic effect of carbohydrate rich sports beverages in nondiabetic athletes [8]. However, very few studies have been conducted in which exercise performance is examined during differing levels of blood glucose concentrations in those with T1DM [9, 10]. In one study, compared with hyperglycemia or euglycemia, exercise capacity was reduced and ratings of perceived exertion increased with hypoglycemia in group of youth with T1DM, although the exercise was always stopped by the research investigators rather than the subjects for safety reasons [10].

In this field study we measured the effects of concurrent and antecedent (nocturnal) blood glucose levels on sport performance in youth with T1DM participating in a one-week sports day camp. We hypothesized that, compared with euglycemia, both hypo- and hyperglycemic states would result in deterioration of sporting skill performance.

2. Methods

2.1. Participants. Children and adolescents aging 9–17 years were recruited from the 2009 York University Diabetes Sports Camp. To be eligible for the study, subjects had to be clinically diagnosed with T1DM and be on insulin therapy. Exclusion criteria were (1) another serious chronic illness impacting one's ability to perform the sporting activity; (2) a significant developmental delay with an inability to understand the testing protocol; (3) visual colour blindness or the use of medications (other than insulin) known to affect glycemic control.

Twenty seven youth with T1DM (15 males, 12 females), 9–17 years of age, agreed to participate. This represents 90% of those approached for the study. The mean age of subjects was 11.4 ± 1.9 years, duration of diabetes ranging from 1–13 years. Twenty four of these individuals agreed to participate in the Stroop testing, and seventeen agreed to overnight continuous glucose monitoring (CGM). Since not all subjects were fitted with the CGM at once, due to the availability of units, the continuous glucose data shown below for days 2 and 4 of the camp are for $n = 11$ and $n = 10$ subjects, respectively. The study was approved by the York University Human Participants Research ethics board.

2.2. Study Procedures. All data collection took place in a field study setting from Monday July 20th to Friday July 24th, 2009 at the sports camp.

2.2.1. Sports Skill Assessment. Sport skill testing took place repeatedly for all participants starting on the second day of camp (Tuesday) lasting until the last day of camp (Friday). All sport skills were demonstrated by certified coaching staff on the day before testing and participants were encouraged to practice in order to limit a learning effect. In all cases, participants were instructed as to how the sports skill scoring would be calculated prior to their first test. Participants were evaluated on tennis, basketball, or soccer abilities in a structured manner. Participants performed skill testing in one sport only (i.e., the sport that they chose to focus on for the entire week). Participants were brought to the assessment stations at random points during the camp day and completed an average of 6 ± 1 tests during the week. Tennis assessments took place on full sized courts and involved the instructor consecutively volleying 15 balls in a standardized manner and points were scored for volleys returned by the participant. Basketball testing took place inside a university gymnasium with subjects standing 13 feet from the backboard of the net.

Participants were given one minute to complete up to 15 shots and scoring was based on the number of baskets made. The soccer assessment involved participants kicking 10 balls into a series of three different sized soccer nets. Balls were lined up 13′ away from and parallel to the goal line. Three points were awarded for balls scored into the smallest net, two points for balls into the medium sized net, and one point for balls into the large net. If a ball struck the frame of the medium or smallest size net, the ball was counted as if it had entered the net a size larger. Final scores were calculated by subtracting the time taken to kick all ten balls (in seconds) from points scored.

2.2.2. Blood Glucose Measurements and Categories. For safety reasons, no subject was asked to perform a sport skill if they felt symptoms of hypoglycemia. In general, participants performed routine self-glucose monitoring before meals and sometimes (e.g., those on pump therapy) before snacks. In addition, if symptoms of hypoglycemia were noted by the campers at any time during the camp, blood glucose was immediately tested and treated as required (i.e., 15 grams of fast acting dextrose tablets- Dex4, Can-Am Care, Montreal, Qu).

Blood glucose measurements were also taken and recorded immediately following all sports skill assessments using a standard glucose meter (One Touch, LifeScan Inc, New Brunswick, NJ). Thus, both the subjects and the coaching staff were blinded to the glucose levels at the time of skill evaluation. For all skills, scores were categorized into hypoglycemia (<3.6 mmol/L), acceptable glycemic range, (3.6–13.8 mmol/L), or hyperglycemia (≥13.9 mmol/L). These categories were set a priori. The hypoglycemic range was based on a recent article [11] recommending that ≤3.5 mmol/L is a clinically relevant definition of hypoglycemia. Acceptable glycemic ranges for exercise participation, for those with T1DM, are typically recommended to be between 4.0 and 13.9 mmol/L, but participation is deemed safe if individuals are hyperglycemic but without ketoacidosis [12]. In order to compare data across all sports, participant's scores were converted to a percentage of their own personal best.

2.2.3. Nocturnal Hypoglycemia. Overnight hypoglycemia was measured using the Medtronic iPro continuous glucose monitoring device, which measures interstitial glucose levels every 5 minutes [13]. This technology uses a thin enzyme-coated electrode catheter inserted as a "sensor" just under the skin of the abdomen or the upper arm. The reaction between interstitial fluid glucose and glucose oxidase located on the electrode produces hydrogen peroxide. This reaction converts the interstitial glucose into an electrical current proportional to the glucose concentration at the site of the catheter insertion. The iPro device is small, inconspicuous, and can be worn in virtually all sporting activities including swimming. This particular "professional" CGM devise does not show "real time" glucose values but converts interstitial fluid glucose concentrations to whole blood glucose concentrations once it is removed (usually after 72 hours of data collection) and the information is downloaded. As such, subjects and the investigators are blinded to the sensor data while wearing it. This technology has previously been shown to have the capacity to detect both nocturnal glucose levels, while the individual is sleeping, and glycemic excursions associated with exercise [13]. Product specialists inserted the devices from the Monday to the Wednesday of the camp and instructed the subjects on proper protocol for calibration with their own blood glucose monitor. Data recorded from the iPro were analyzed from 10 pm to 6 am for assessment of nocturnal hypoglycemia. Nocturnal biochemical hypoglycemia was defined as any interstitial glucose concentration ≤3.9 mmol/L on at least two consecutive five minute averages. The glucose iPro reading at 9:30 pm on nights when nocturnal biochemical hypoglycemia occurred (if it did occur) was compared to the mean at the same time on nonhypoglycemic nights using a student's t-test. Hyperglycemia (≥13.9 mmol/L) was also documented from 10 pm–6 am in an identical way. Subjects recorded at least 4 capillary blood glucose measurements, as measured by the glucose monitors, per day during the period between 0900 h and 1600 h for calibration purposes.

2.2.4. Stroop Test Assessment. Age appropriate commercially available Stroop Colour and Word Tests (PAR, Inc, Lutz, Fla) were used to assess cognitive processing at different blood glucose concentrations [14]. The Stroop test is a commonly used clinical tool that measures selective attention, speed of functioning, and other psychological capacities that are affected by attentional fatigue. During the test, participants are asked to recite the name of the color that a word is printed (e.g., "blue," "green," or "red" ink) and not the word itself, which is a name of a color (e.g., the word "red" printed in blue ink instead of red ink). Naming the color of the word during this "interference" takes longer and is more prone to errors than when the color of the ink matches the name of the color [15]. Scores are determines for reading ability, color recognition and interference, with the latter an index of the capacity to maintain attention during the interference caused by the color changes in the typed words.

Stroop testing took place from Monday to Friday (inclusive) and subjects completed an average of 5 ± 1.4 tests, each test lasting ∼2–5 minutes. Willing participants were randomly brought to the "sidelines" for testing during the sports camp. Subjects carried out blood glucose measurements on a glucometer immediately following testing. Reading, color naming, and interference scores were converted to T-scores for their age according to the Golden Stroop manual and then grouped into the same blood glucose ranges as sports performance and analyzed using the same methods.

2.2.5. Statistics. Values are reported as means ± standard deviations. A Type 3 orthogonal one-way ANOVA was used to compare overall sporting skill scores and Stroop score (both expressed as a percent of personal best) across the three blood glucose categories (hypo, euglycemia, hyperglycemia), followed by a fisher-LSD post-hoc test if a main effect of blood glucose concentration was found. A paired student's t-test was used to compare the average for the percentages of personal best scores on days following a bout of nocturnal hypoglycemia to the mean following a night without nocturnal hypoglycemia. Statistical analysis was carried out using Statistica 6.0 statistical software package (StatSoft, Tulsa, OK).

3. Results

3.1. Sports Skills and Blood Glucose Levels. Sport skills were performed daily (Tuesday through Friday) by each subject at varying time points throughout the day, with an average of 6 ± 1 sports skill test done per subject over the course of the week, thus giving a total of ∼160 sports skill tests. Because of the field study design, all subjects were tested while in acceptable glycemic range ($n = 27$), while only a portion of the subjects were tested while hypoglycemic ($n = 7$) or hyperglycemic ($n = 10$). The mean capillary blood glucose concentration during hypoglycemic testing was 3.1 ± 0.4 mmol/L, during the acceptable glycemic range was 7.6 ± 2.7 mmol/L, and during hyperglycemia was 17 ± 3.2 mmol/L. All data was expressed as a percentage of their personal best score to help account for the widely varying skill level among the subjects. Mean sport skill performance was highest when blood glucose values were in the acceptable glycemic range (3.6–13.8 mmol/L), with subjects performing 79 ± 9% (mean ± SD) of their personal best (Figure 1). Compared with the acceptable performance range, sports skill performance was lower during hypoglycemia (64 ± 20%, $P < .05$ versus euglycemia) but

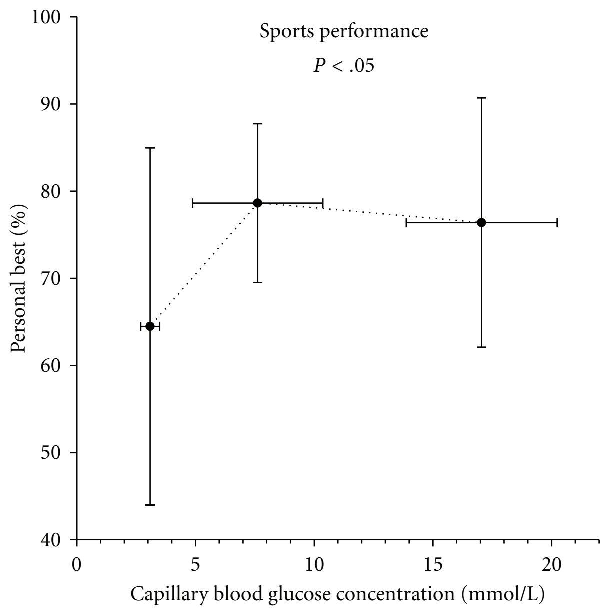

Figure 1: Sports skill performance score at each of the three categories of glycemia. Scores are shown as a percentage of personal best during the week. Scores during hypoglycemia were significantly lower than euglycemia or hyperglycemia. See methods section for a complete description. Mean ± SD. A significant main effect of glucose category on performance was found. Post hoc analysis reveled that performance in hypoglycemia was less than euglycemia and hyperglycemia at $P < .05$.

similar during hyperglycemia (76 ± 14). Of the 7 subjects tested while hypoglycemic, 1 subject scored his personal best during hypoglycemia. Three of 10 subjects performed best while hyperglycemic, while the remaining 24 subjects performed their personal best while in the acceptable glycemic range.

3.2. Daytime Glucose Concentrations as Measured by CGM. Interstitial glucose levels on day two and day four of the sports camp are shown in Figures 2(a) and 2(b), respectively. As expected, wide variation in glucose control was observed on both days. In general, mean glucose levels were largely within the acceptable range during the day but decreased during the morning activities. Glucose values increased post lunchtime and then decreased again in the afternoon. Four of eleven (36%) subjects had hypoglycemia (<3.6 mmol/L) at some point during the camp hours (9 AM–4 PM) on day 2 (9 AM–4 PM), while seven of ten (70%) subjects had hypoglycemia at some point during day 4. Duration of hypoglycemia ranged from 15 minutes to 2.5 hours.

In a separate analysis of iPro accuracy during the camp, 26 hypoglycemic glucometer readings were compared to the subject's corresponding iPro readings. The time difference between the two readings was always less than 2.5 minutes because the iPro produces a new reading every 5 minutes. The iPro overestimated glucose compared to the glucometer 13 times (50%), underestimated twice (8%), and was within 20% of the glucometer 11 times (42%).

3.3. Nocturnal Hypoglycemia as Measured by CGM. Figures 2(c) and 2(d) document nocturnal glucose levels during nights 2 and 4 of the camp. Table 1 shows the incidence of nocturnal hypoglycemia over the 4 nights of the camp. As shown in Table 1, nocturnal hypoglycemia often reoccurred in subjects. Of the 11 subjects with multiple overnight iPro data, 8 subjects (∼73%) had multiple nights with hypoglycemic events, 1 subject (∼9%) had a single night with hypoglycemia, while only 2 (18%) participants did not develop hypoglycemia. Forty one of the 45 nocturnal hypoglycemic events recorded had glucose levels <3.6 mmol/L, indicating that the incidence of moderate to severe hypoglycemia was common on the evening following sports camp participation. Twelve subjects with nocturnal hypoglycemic events completed sports skill testing on the day following the event compared with 9 subjects performing skill assessment on days without preceding nocturnal hypoglycemia. Performance did not differ between these conditions, including when blood glucose concentrations during assessments the following day were controlled for in the analysis.

3.4. Stroop Testing. Stroop testing was done repeatedly on all subjects throughout the week. Because of the field study design, not all subjects were tested during hypo- ($n = 7$) and hyperglycemia ($n = 9$), although all 24 subjects were measured during the acceptable participation range. Reading ability was lower during hypoglycemia (56 ± 5% of personal best) than either euglycemia (64 ± 7%) or hyperglycemia (63 ± 9%, $P < .05$) (Figure 3(a)). Only 1 of 7 subjects read best during hypoglycemia, while 3 of 9 performed best during hyperglycemia. Similarly, color naming also tended ($P = .06$) to be lower during hypoglycemia (47 ± 12% of personal best) compared to either euglycemia (55 ± 7%) or hyperglycemia (52 ± 11%, Figure 3(b)). Two of 7 subjects had highest color recognition scores during hypoglycemia, while 6 of 9 had highest recognition during hyperglycemia. Interference score was also lower during hypoglycemia (43 ± 13%) but not during hyperglycemia (51 ± 8%), compared with euglycemia (50 ± 5%, $P < .05$, Figure 3(c)). Five of 7 subjects had their lowest interference score during hypoglycemia, while 5 of 8 had their lowest score during hyperglycemia.

4. Discussion

This field study, conducted in a unique sports skills camp for youth with type 1 diabetes, shows that the ability to carry out fundamental sports skills is markedly reduced by hypoglycemia compared with either euglycemia or hyperglycemia. This decrement in sports performance with hypoglycemia mirrors the decrement in cognitive performance in these adolescents, as assessed by the Stroop task protocol. In contrast to the finding that acute hypoglycemia influences performance, however, we found no evidence that a prior bout of nocturnal hypoglycemia influences sport skill performance the following day. This study is the first to examine sports performance associated with different levels of blood glucose levels in adolescents with type 1 diabetes. This is

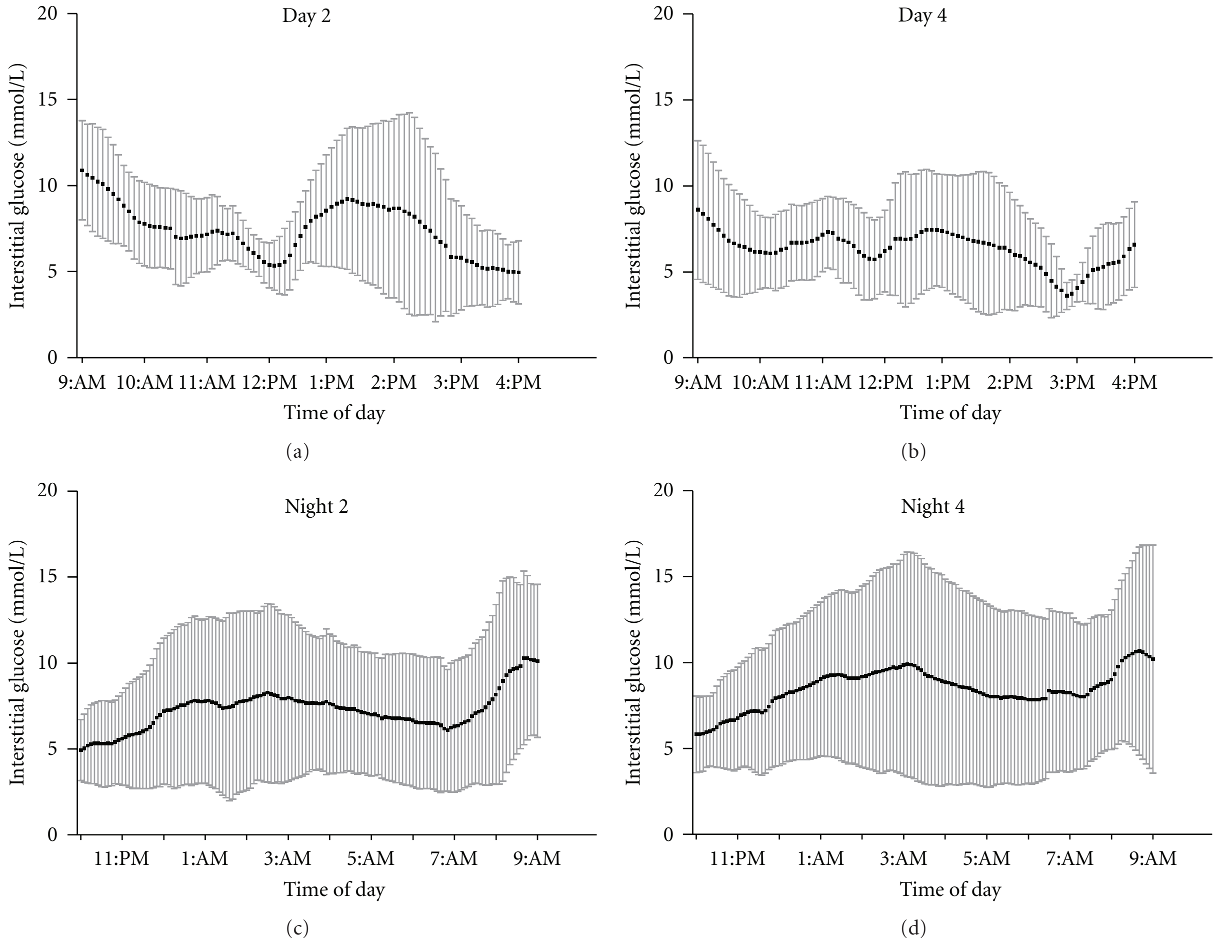

Figure 2: Interstitial glucose levels during day 2 ((a) $n = 8$) day 4 ((b) $n = 10$), evening 2 ((c) $n = 8$), and evening 4 ((d) $n = 10$) of the sports camp. Mean ± SD.

Table 1: Occurrences of nocturnal biochemical hypoglycemia during the evenings of the sports camp.

Night	Subjects (n)	Ratio of participants with nocturnal hypoglycemia	No. of nocturnal hypoglycemic events	No. of subjects with multiple nocturnal hypoglycemic events	Duration of nocturnal hypoglycemic events in minutes (mean ± SD)	Median duration of nocturnal hypoglycemic events in minutes
1	14	8/14	12	3	98 ± 116	50
2	8	5/8	11	4	97 ± 124	35
3	12	9/12	16	3	70 ± 92	30
4	8	5/8	6	1	89 ± 100	43

also the first study to measure nonendurance type sport performance in persons with type 1 diabetes.

Previously, we found that endurance cycling capacity is greater, and ratings of perceived exertion lower, when blood glucose levels are prevented from dropping to hypoglycemic ranges by providing exogenous carbohydrate in the form of a sports beverage [10]. However, our prior findings may have been contaminated by an order effect as exogenous glucose was always given during the second cycling test and the study investigators were not blinded to the blood glucose levels of the subjects, in part for ethical/safety reasons. In eight endurance-trained adults with T1DM, elevating blood glucose levels from 5.3 ± 0.6 mmol/L to 12.4 ± 2.1 mmol/L, via hyperinsulinemic glucose clamp technique, failed to change peak power output or other physiological endpoints such as lactate, heart rate, or respiratory exchange ratio [9]. Overall, these laboratory-based studies are limited; however, as performance was only measured during stationary cycling

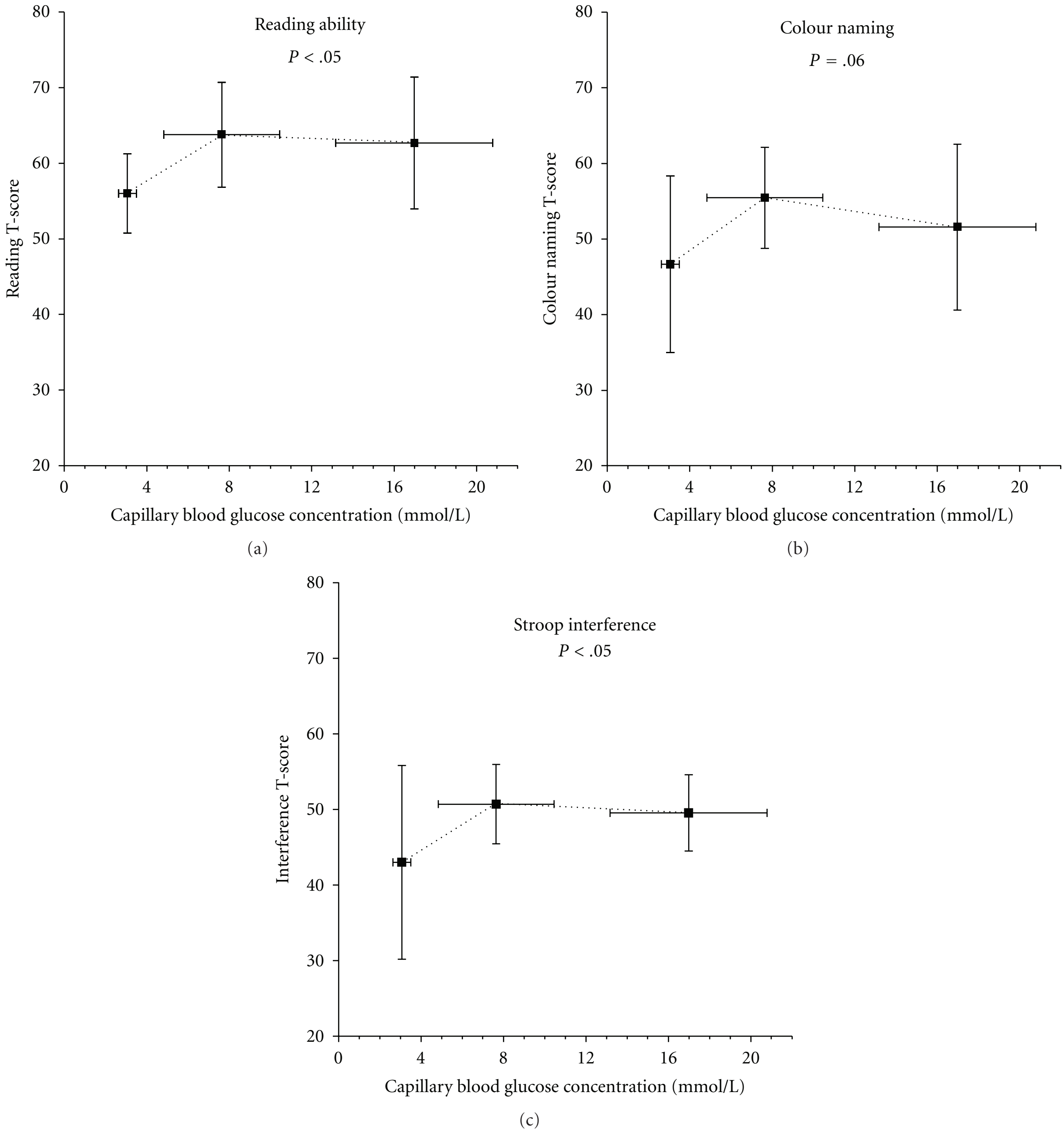

FIGURE 3: Stoop skill performance scores at each of the three categories of glycemia. Scores are shown as a percentage of personal best during the week. Scores during hypoglycemia were lower than euglycemia or hyperglycemia in reading ((a) $P < .05$), color recognition ((b) $P < .05$), and interference ((c) $P = .06$). See methods section for a complete description. Mean ± SD.

and not during sporting tasks that require a certain level of cognitive processing, reaction time, and motor skill performance.

Hypoglycemia has long been thought to influence cognitive function in youth with diabetes. A recent field study of school-aged children with type 1 diabetes has shown that detrimental cognitive effects, as measured by math test performance, occurs when blood glucose levels are either hypo- or hyperglycemic [16]. Similar to their finding of an inverted U shape relationship between glycemia and cognitive performance, with the best performance in the euglycemic range, our study clearly demonstrated the negative effects of hypoglycemia on sports skill performance. Importantly, this finding of significantly impaired sports performance with hypoglycemia appeared universally across nearly all subjects, as only one subject performed better while hypoglycemia compared to euglycemia. Nonetheless, it is clear that the magnitude of the decrement of sport performance was highly individual with some subjects only showing minor reductions while others showing greater impairment. The reasons for the wide variation in sports skill performance during hypoglycemia are unclear but may be related to the level of blood glucose concentration, the rate at which glucose was dropping, the experience of the individual competing during hypoglycemia, or their capacity to maintain focus.

The detrimental effects of hypoglycemia on cognitive function are well documented in the literature [17]. We chose to make use of the child-specific Stroop test to asses the effect of glycemia on neuropsychological performance during the sports camp. The Stroop Test evaluates the ability to view complex visual stimuli and to respond to one stimulus dimension while suppressing the response to another dimension, an "executive" skill largely attributed to frontal lobe function [14, 15]. We found that reading and color recognition ability was more susceptible to impairment by hypoglycemia than interference score. In fact, we found that interference score was reduced during hypoglycemia compared with either euglycemia or hyperglycemia, indicating that hypoglycemia improved the capacity to maintain concentration during interference. An increased interference effect is found in disorders such as brain damage, dementias, and other neurodegenerative diseases, attention-deficit hyperactivity disorder, and a variety of mental disorders such as schizophrenia, addictions, and depression. As pointed out above, a lower interference score would usually be indicative of greater attention, however, given the neural insult of hypoglycemia this interpretation is likely not the case. A possible explanation for reduced interference suggested by the Stroop test is that there is poor dominance of the word naming system over the color naming system [14]. Although both color naming and word processing were impaired during hypoglycemia, the insult to the word processing system may be greater. This hypothesis requires further investigation, however.

Studies analyzing the cognitive impairment associated with hyperglycemia typically see a decline in ability at blood glucose levels >20 mmol/L [16]. Our failure to observe a similar deterioration in sports skill performance with hyperglycemia may have been due to the fact that the mean blood glucose concentration in our subjects were lower (16.9 ± 3.17 mmol/L) than what had been tested with cognitive function previously. Interestingly, a prior study in adults with type 1 diabetes found no change in endurance performance with mild hyperglycemia (∼12 mmol/L) compared with euglycemia [9]. It is important to note that the hyperglycemia observed in our subjects was typically transient in nature, as evidenced by the CGM tracings, and perhaps a result of brief elevations in circulating catecholamines associated with the exercise itself. Indeed, it is likely that performance skill would decline if the level of hyperglycemia was higher or for a prolonged duration (days rather than minutes to hours), since individuals would be expected to be suffering from dehydration, ketosis, and reduced muscle and liver glycogen content [18]. However, this hypothesis requires further investigation.

Whether nocturnal glycemia influences either cognitive or sports performance the next day remains unclear. Previously, cognitive tests based on acute stimulus processing have failed to find a detrimental effect of preceding nocturnal hypoglycemia on cognition [19, 20]. Similarly, unlike concurrent hypoglycemia, we found that nocturnal hypoglycemia did not affect sports skill performance the following day. Even if sport skill performance is not influenced by antecedent hypoglycemia, *per se*, it is important to note that endurance exercise capacity may be impaired because of a higher risk for autonomic dysfunction and repeat hypoglycemia [21]. Future investigation is required, however, to compare endurance exercise performance using some measure of exercise capacity after a night of hypoglycemia versus euglycemia.

We found that the iPro device tended to overestimate blood glucose concentrations when subjects were deemed to be hypoglycemic, as measured by capillary finger stick/glucometer readings (i.e., 50% of the time in 26 paired valued). This overestimation in blood glucose levels with CGM was likely due to the lagging of sensor reported glucose changes behind blood glucose changes during exercise, as has been reported previously [22, 23]. It is worth noting that blood glucose meters also have approximately a 20% variance compared to plasma glucose as measured by a clinical devise, such as a YSI analyzer, and these paired values would be susceptible to variance in both the iPro and glucometer readings. Importantly, unlike the iPro devise used in this study, other "real-time" CGM devises have live glucose display and hypoglycemic alarm functions that can be set to alert the users when their sensor measures a certain glucose concentration. It is important to note that if the threshold for hypoglycemia in the real-time CGM units is set at 5.0 mmol/L, rather than 3.9, then, based on our study, ∼85% of the hypoglycemic events would be caught by the sensor.

This study has a number of important limitations that should be pointed out. First, the sports skill tests conducted were of relatively short duration (∼1-2 minutes) and thus do not demonstrate how blood glucose levels affects mental and physical stamina (i.e., endurance capacity). Second, because of the field test design of the study, few subjects were testing in all three conditions (hypo, euglycemia, and hyperglycemia) and thus a repeated measured design could not be used for the analysis. Future studies may wish to clamp blood glucose levels at varying levels (hypoglycemia, euglycemia, and hyperglycemia) in a counterbalanced design so that a repeated measures design approach could be performed.

In summary, we found that hypoglycemia, but not hyperglycemia, impairs sports skill performance and cognitive function in youth with type 1 diabetes. In contrast, prior exposure to hypoglycemia the night before competition does not appear to influence performance the following day. As such, vigilance in glucose control that limits hypoglycemia during sport should maximize competitive capacity in adolescents with type 1 diabetes. In addition, any obvious decrement in sport performance, such as poor passing, failed free throws, serves, and so forth; should be a warning sign to young athletes with diabetes to check for hypoglycemia by monitoring their blood glucose levels and treat hypoglycemia with additional carbohydrate intake.

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Review Article

What Limits Cardiac Performance during Exercise in Normal Subjects and in Healthy Fontan Patients?

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Exercise is an important determinant of health but is significantly reduced in the patient with a univentricular circulation. Normal exercise physiology mandates an increase in pulmonary artery pressures which places an increased work demand on the right ventricle (RV). In a biventricular circulation with pathological increases in pulmonary vascular resistance and/or reductions in RV function, exercise-induced augmentation of cardiac output is limited. Left ventricular preload reserve is dependent upon flow through the pulmonary circulation and this requires adequate RV performance. In the Fontan patient, the reasons for exercise intolerance are complex. In those patients with myocardial dysfunction or other pathologies of the circulatory components, it is likely that these abnormalities serve as a limitation to cardiac performance during exercise. However, in the healthy Fontan patient, it may be the absence of a sub-pulmonary pump which limits normal increases in pulmonary pressures, trans-pulmonary flow requirements and cardiac output. If so, performance will be exquisitely dependent on pulmonary vascular resistance. This provides a potential explanation as to why pulmonary vasodilators may improve exercise tolerance. As has recently been demonstrated, these agents may offer an important new treatment strategy which directly addresses the physiological limitations in the Fontan patient.

1. Introduction

Exercise is an important determinant of health and provides numerous cardiovascular, psychological, and prognostic benefits [1]. The Fontan operation, and its refinements, have proved a major success with a majority of patients with univentricular malformations now surviving into adulthood with a good quality of life [2]. However, exercise tolerance is significantly reduced and the factors responsible for this exertional limitation are incompletely understood. This paper aims to provide a unique perspective on the limitations of the Fontan circulation by focusing on exercise constraints in a normal biventricular circulation. Rather than describing abnormalities within the components of a Fontan circulation, we will focus on highlighting the importance of that which is missing—a prepulmonary pump. Popular models of exercise physiology have concentrated on the systemic circulation and the left ventricle (LV) as the primary determinant of cardiac output (CO) augmentation during physical exertion [3]. These models are likely to be accurate in patients with heart failure. However, in the healthy subject, there is a large reserve for exercise-induced augmentation of the systemic ventricle and vasculature. A less commonly cited determinant of cardiac performance during exercise is the "lesser circulation" of the RV and the pulmonary circulation [4–6]. We will discuss the evidence supporting the concept that the right ventricle (RV) is a determinant of exercise performance and that, in its absence, pulmonary vascular resistance becomes a critical limitation. The recent availability of relatively specific pulmonary vasodilators has given these physiological discussions immediate clinical relevance. The potential benefit of these agents [7] is consistent with physiological theory and represents an exciting avenue of investigation in Fontan patients.

2. Cardiac Output Augmentation during Exercise in the Normal Heart

Exercise performance is defined by the ability of the body's working muscles to utilize oxygen, and this can be measured by VO_2 max on cardiorespiratory testing. It has been demonstrated that the skeletal muscles' ability to utilize oxygen far exceeds the capacity of the cardiovascular system to deliver oxygen [8]. Thus, cardiac output (CO) becomes the limiting step, and explains 70%–85% of the variance in VO_2 max with the remainder being determined by peripheral factors such as mitochondrial density which enables greater oxygen extraction [9]. In healthy subjects, CO may be expected to increase 3- to 5-fold whilst increases are even greater in athletes. Cardiac output is enhanced by (1) greater preload, (2) increased heart rate, (3) increased myocardial contractility, and (4) reduced afterload during exercise, and both ventricles need to generate the same stroke volume. Thus we can speculate as to what is the "weak link" by asking which factor is closest to its physiological limit during exercise. Conventional teaching is that it is the LV and its interaction with the systemic circulation which determines cardiac output. However, LV functional measures and measures of systemic vascular tone have not been shown to predict exercise performance as might be expected if they were the limitation of exercise performance [10–12].

2.1. Preload and Exercise. Preload may be defined as the passive stretch applied to the myocardium prior to the initiation of active contraction. According to the Frank-Starling mechanism, increases in preload augment cardiac output. The extent to which this mechanism contributes to exercise-induced CO augmentation remains a point of debate. Studies using radionuclide ventriculography have reported large increases in LV end-diastolic volume during exercise and minimal or no decrease in LV end-systolic volume. Warburton et al. [13, 14] suggested that this increase in LV preload was the dominant means by which CO increased during exercise, especially in well-trained athletes [13, 14]. However, more recent exercise studies using 2D echocardiography [3, 15–19] and cardiac magnetic resonance (CMR) [20–22] have found little or no increase in LV end-diastolic volume and that augmentation of stroke volume is primarily due to decreases in LV end-systolic volume. Assimilating these contrasting findings is difficult, but perhaps a reasonable summary may be that enhanced LV preload contributes to, but is not the sole determinant of, exercise-induced increases in stroke volume.

Accepting the contribution of LV preload in cardiac output augmentation, the question arises as to what determines LV preload? This is seldom discussed in the literature. It is often assumed that the LV generates flow which then serves as its own preload with, perhaps, some facilitation from skeletal muscle acting to enhance venous return. With a few notable exceptions [4–6, 23], the RV and pulmonary circulation have rarely been considered as potential constraints on LV filling in normal exercise physiology. We speculate that its importance may have been underappreciated. At least in settings where RV afterload is increased, reduced flow in the presystemic circulation can result in reduced LV preload and, thus, cardiac output limitation. Holverda et al. [20, 21] demonstrated reduced LV filling during exercise in patients with pulmonary hypertension and obstructive airways disease. Also, the demonstration of improved exercise tolerance with pulmonary vasodilators provides some indirect affirmation of this concept. It has been shown that sildenafil [24, 25] and bosentan [26] can increase exercise performance at altitude or during hypoxic exercise although no benefit has been demonstrated in normoxic settings. It was concluded by Faoro et al. [26] that the pulmonary circulation provides a limitation to cardiac output when there is hypoxic pulmonary vasoconstriction. The lack of efficacy of selective pulmonary vasodilators during normoxic exercise may suggest that pulmonary vasodilation is close to maximal in this setting [27].

Frequently, exercise intolerance is attributed to diastolic dysfunction, and it is implied that the LV filling impairment is due to pathology of the LV myocardium. However, it is important to note that it is extremely difficult to differentiate impaired filling due to myocardial stiffness from that due to reduced preload when using noninvasive measures [28]. Echocardiographic measures are similar when there is a lack of "push" from reduced preload and when there is a lack of "suck" from LV impairment. Puwanant et al. described reductions in traditional and novel diastolic measures in patients with pulmonary hypertension despite relatively normal LV function [28]. Hart et al. reported measures of diastolic dysfunction which were associated with preload reduction following marathon running. These changes normalized immediately with preload augmentation by leg lifting [29]. Finally, in a large cohort of patients with obstructive pulmonary disease, Barr et al. attributed impaired LV filling to preload reduction through increased pulmonary vascular resistance rather than myocardial stiffness resulting from hypoxia or hypertension [30].

2.2. Afterload and Exercise. Afterload can be defined as the myocardial stress achieved during contraction, the major determinants being systolic pressure, cavity size, and wall thickness [31]. Decreases in LV afterload serve to increase stroke volume and this has been emphasized as an important source of cardiac output modulation in popular models of exercise physiology. It has even been suggested that the exercise-induced decreases in systemic vascular resistance (due to vasodilation in skeletal muscle) is the primary determinant of CO augmentation, and that the resultant increases in heart rate and contractility are simply a compensation to maintain systemic blood pressures [32, 33]. However, it has been well established that the capacity for peripheral vasodilation far exceeds the capacity for cardiac output augmentation, implying that the limitation to cardiac output is upstream of the peripheral circulation [34].

Characterization of RV afterload during exercise is more difficult because its measurement requires invasive pulmonary artery catheterization or echocardiographic estimates, both of which can be challenging during exercise. Whilst it is commonly stated that pulmonary artery pressures increase only slightly with exercise [35, 36], multiple studies have reported considerable increases in pulmonary artery pressures [4, 23, 37–42]. Kovacs et al. [42] combined data from nearly 200 patients in invasive studies to demonstrate that mean pulmonary artery pressures increased in a linear

Table 1: Comparison of exercise-induced changes in pulmonary versus systemic vascular resistance and pressure. The pulmonary vasculature has very low resistance at rest but relatively limited capacity for further reduction. Therefore, exercise-induced increases in flow result in greater pressures due to the inability to compensate by reducing resistance. As described by the simplified Poiseuille's law: Pressure = Flow × Resistance.

	Left Ventricle	Right Ventricle
Rest		
Cardiac Output (L/min)	5	5
Vascular resistance (dyne-sec·cm^5)	1100	70
Afterload Pressure (mmHg)	130/75 (85)	25/9 (15)
Exercise		
Cardiac Output (L/min)	25	25
Vascular resistance (dyne-sec·cm^5)	↓↓↓	↓
Afterload Pressure (mmHg)	↑	↑↑↑

manner with exercise which explains why relatively high pressures have been measured in those with good exercise tolerance. Argiento et al. [37] described exercise-induced increases in systolic pulmonary artery pressures that frequently exceeded 60 mmHg in healthy subjects whilst Bidart et al. [39] reported even greater increases in athletes. It may be that these increases in pulmonary artery pressures are a result of an inability for the pulmonary vasculature to reduce its resistance sufficiently to compensate for the increased CO of exercise. This concept is best summarized by the simplified Poiseuille's relation in which CO is proportional to pressure and inversely to resistance [3]. Pulmonary vascular resistance is very low at rest and previous studies have suggested that its capacity for reduction is only 20%–50% [23, 35, 43]. This represents a marked difference to the systemic circulation where greater reductions in peripheral resistance moderate increases in LV afterload (see Table 1).

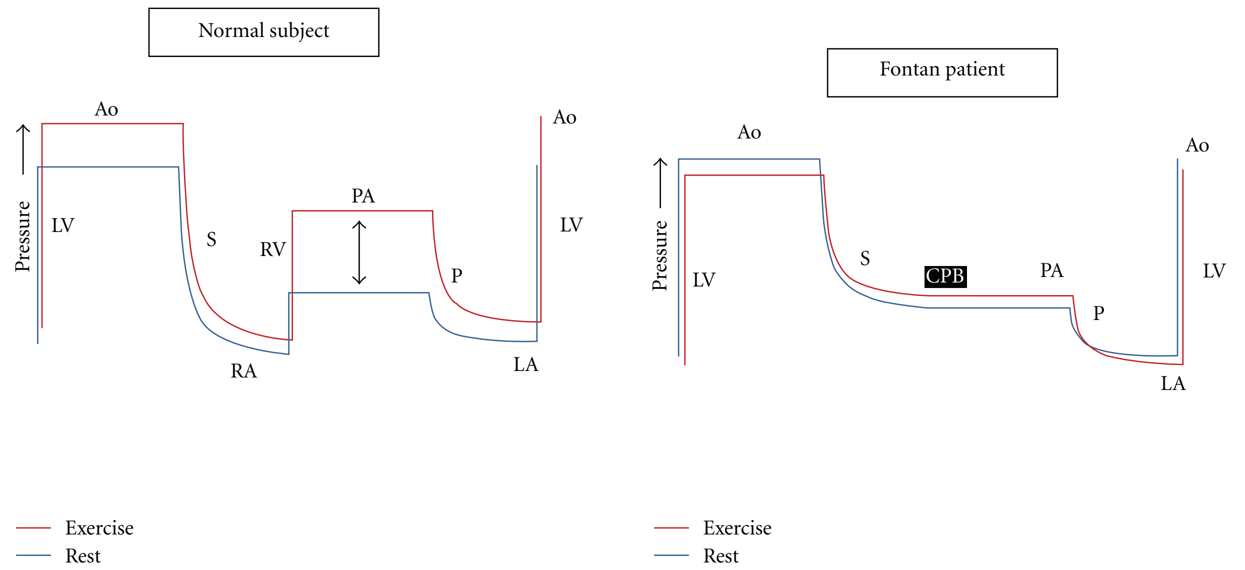
2.3. Contractility and Exercise. Contractility is an intrinsic property of the myocardium, is load independent, and is most frequently derived from invasive indices such as the slope of the end-systolic pressure volume relation or the preload recruitable stroke work [44]. There are no studies which have assessed and compared LV and RV contractility during exercise in healthy subjects. At rest, RV measures of mass [45] and contractility [46] are one-third to one-fifth those of the LV and this appropriately matches the pressure requirements of each [47]. However, when RV afterload increases, RV contractility may be unable to maintain ventriculo-arterial coupling such that cardiac output declines. MacNee [48] described marked reductions in RV stroke volume (∼30%) when pulmonary artery pressures doubled and compared this with only slight decreases in LV stroke volume with physiological increases in mean arterial pressures. During exercise, Morrison et al. [23] used first-pass radionuclide ventriculography and invasive pressure measures to demonstrate a progressive improvement in RV ejection fraction with exercise-induced reductions in pulmonary vascular resistance. However, in comparison with the systemic circulation, increases in pulmonary vascular pressures were relatively greater, and reductions in vascular resistance were less. This would suggest that exercise results in a disproportionate workload for the RV, a concept which is further supported by the demonstration that cardiac fatigue predominantly affects the RV after intense prolonged exercise [49, 50]. Therefore, there are reasonable grounds to contend that exercise-induced increases in RV load represent a potential for cardiac output limitation. For cardiac output to be maintained during exercise, the RV must greatly augment its contractility, possibly more so than the LV. As will be discussed, this is problematic for exercise performance when RV function is reduced or absent.

2.4. Heart Rate and Exercise. Heart rate is a major determinant of cardiac output, particularly in the later phases of exercise when stroke volume augmentation plateaus [3]. It is, however, inefficient for the heart rate to increase such that LV filling is impaired. Thus, although the factors which determine maximal heart rate during exercise are incompletely understood, it is likely that cardiopulmonary baroreceptor activation contributes to maintaining an appropriate balance between LV preload and heart rate during exercise [51].

3. The Healthy Fontan Patient and Exercise: How Is Reduced Exercise Capacity Explained?

In the Fontan circulation, the systemic and pulmonary vascular beds are connected in series without the presence of a pre-pulmonary pump to add forward energy to flow through the lungs (Figure 1). Typically CO in a Fontan circulation at rest is decreased to 70% (range 50%–80%) of normal and an increase in peripheral oxygen utilization compensates for this reduction in oxygen supply [52]. During exercise, oxygen utilization remains normal or supranormal but maximal CO is approximately half that of normal [53]. Control of cardiac output in a Fontan circulation is complex with a different interplay of contractility, afterload, preload, and heart rate [54]. The implications of exercise on each of these variables will be discussed and contrasted with that already described for normal subjects.

3.1. Preload and Exercise in the Fontan Patient. There is limited data in which LV filling during exercise has been assessed in the Fontan patient. More frequently, studies have assessed the hemodynamic response to low-dose dobutamine as an exercise surrogate. Senzaki et al. [55, 56] have twice demonstrated limitations in preload reserve in this setting. They demonstrated a significant 25% reduction in LV end-diastolic pressure in the Fontan patient whereas there was no change in subjects with normal circulation [56]. Using variables derived from ventricular pressure-area hybrid loops, they found that cardiac index was dependent upon preload (end-diastolic area) and not contractility (ventricular elastance) or afterload (arterial elastance). Thus, inadequate preload reserve was implicated in the failure for CO to augment with β-adrenergic stimulation. Robbers-Visser et al. [57] used CMR imaging to provide a volumetric assessment of dobutamine-induced cardiac augmentation in



(a) (b)

Figure 1: Theoretical schema to illustrate circulatory pressure changes in normal and Fontan patients at rest and during exercise. In the normal circulation, pressure is generated in the systemic ventricle (LV) to produce flow in the aorta (Ao) and systemic circulation (S). Pressure dissipates across the systemic microcirculation such that right atrial (RA) pressures are low. The pre-pulmonary pump (RV) provides the pressure to generate the flow in the pulmonary artery (PA) which then dissipates in the pulmonary circulation (P) but is sufficient to maintain preload in the left atrium (LA). During exercise, systemic vascular resistance falls such that there is little increase in mean LV pressure requirements. However, more substantial pressure increases are required in the RV (purple arrow), and these pressure requirements increase with exercise intensity. In the Fontan patient (below), the cavopulmonary bypass (CPB) does not provide any contractile force and, therefore, flow through the pulmonary circulation is dependent on the pressure difference between the RA and LA. During exercise, trans-pulmonary flow can only be augmented by reductions in pulmonary vascular resistance. Beyond mild to moderate exercise, pulmonary vasodilation is maximal and flow increases require a pre-pulmonary pump. Without this, pulmonary pressure does not rise, trans-pulmonary flow does not increase, LA pressure (preload) does not increase, and cardiac output cannot supply the metabolic demands of exercise.

a young group of patients with Fontan circulation. They described a modest increase in CO which was entirely due to increasing heart rate. Stroke volume was unchanged due to the fact that end-diastolic volumes decreased to the same extent as end-systolic volumes. This contrasts with the normal physiological response to dobutamine in which stroke volume increases due to a reduction in end-systolic volume and *preserved* end-diastolic volumes [58, 59]. Thus, CO limitation in the Fontan patient was again attributed to inadequate preload reserve suggesting that the constraint to exercise is “up-stream” of the LV.

As discussed previously, measures of impaired filling should not be regarded as synonymous with LV pathology. Preload reduction and myocardial relaxation impairment will manifest similarly on non-invasive measures such as echocardiography. This is well illustrated in a recent study performed by Goldstein et al. [60] in which echocardiographic indices of diastolic dysfunction were demonstrable in 16 of 28 young Fontan patients. However, hemodynamic data performed in a subset of these patients during exercise demonstrated normal LV filling pressures which did not increase with exercise, a finding which is inconsistent with the raised filling pressures expected with diastolic dysfunction [61, 62]. Rather, these findings again reinforce the concept of preload inadequacy whereby the normal exercise-induced augmentation in LV filling pressures [42] is absent in the Fontan patient.

3.2. Afterload and Exercise in the Fontan Patient. In the Fontan patient during exercise, the reduction in systemic vascular resistance is less than in the normal subject [52]. It is likely that this represents a secondary phenomenon which attempts to maintain blood pressure when CO augmentation is reduced. This is achieved by an increase in sympathetic vasomotor tone [63] but is not always sufficient and BP may still fall in the Fontan patient during exercise [52]. Thus the relatively greater systemic afterload in the Fontan patient is a consequence, rather than cause, of reduced output.

As described earlier, normal exercise is associated with an increase in stroke volume and pulmonary artery pressures. A pre-pulmonary pump is required to generate the pressure and flow which enables adequate LV filling during exercise. Without a pre-pulmonary pump, and without adequate preload, cardiac output cannot increase during exercise. Figure 1 provides a graphic summary of this proposed physiology.

Indirect evidence for our proposition that the pulmonary circulation serves as a limitation to exercise in the Fontan

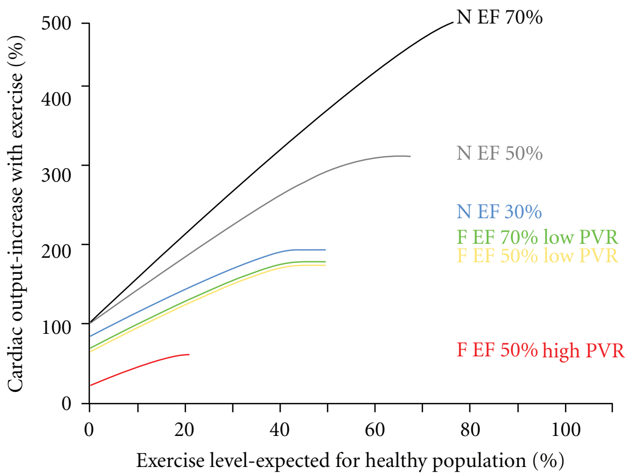


Figure 2: Relationship of output during exercise, pulmonary vascular resistance (PVR), and ventricular function. Cardiac output can increase 5-fold in a normal (N) subject with a biventricular circuit. If ventricular function is impaired, this will first result in decreased maximal output and subsequently in reduced output at low level of exercise. In Fontan patients (F) output is more influenced by PVR than by ventricular function but all have significantly impaired exercise capacity. EF: ejection fraction.

patient is provided by the demonstration that exercise tolerance is improved with pulmonary vasodilators. Giardini et al. [7] studied the exercise response in 18 Fontan patients before and after a single oral dose of sildenafil as compared with a group of 9 control Fontan patients. An improvement in VO_2 max (9.4 ± 5.2%) and cardiac index (10.0 ± 7.2%) was demonstrable in those who took sildenafil whilst these measures were unchanged in those who did not receive treatment. Pulmonary vasodilator therapy warrants further investigation in Fontan patients given its potential to address a likely source of limitation to exercise.

3.3. Contractility and Exercise in the Fontan Patient. There is limited evidence to suggest that contractility serves as a limitation to CO in the Fontan patient, with the exception of those patients with advanced ventricular dysfunction [54]. As described earlier, Senzaki et al. [55] used hybrid measures of ventricular elastance to demonstrate that contractility and contractile reserve were largely preserved in the Fontan patient. Studies that have suggested reduced systolic performance in the Fontan ventricle have frequently based conclusions on measures which are load dependent [64]. Furthermore, if abnormalities of the systemic ventricle and the peripheral circulation were a cause of exercise limitation, a benefit in exercise tolerance might be expected with ACE inhibitor therapy but this has not been demonstrated [65]. Figure 2 summarizes the relative contribution of LV function and pulmonary vascular resistance to exercise-induced increases in cardiac output.

3.4. Heart Rate and Exercise in the Fontan Patient. In the Fontan patient, atrial pacing at increased rates does not result in the augmentation of cardiac output that is seen in normal subjects. Rather, there is a proportional reduction in stroke volume which illustrates heart rate has a less direct effect on CO than in a normal circulation [66]. During exercise, Fontan patients exhibit chronotropic incompetence with a heart rate consistently lower than normal controls, and this has typically been attributed to abnormal reflex control of heart rate or adrenergic dysfunction [67–71]. However, preload inadequacy in the Fontan patient may lead to reducing stroke volume if the ventricular filling time decreases with increasing heart rate. Thus, it is possible that chronotropic incompetence is an *adaptive* response to prevent hemodynamic compromise in patients with limited preload, such as in the Fontan patient [72, 73].

4. Summary

Traditional models of exercise physiology have emphasized the performance of the systemic ventricle and systemic circulation. In the Fontan patient with pathology of the systemic ventricle, these abnormalities will largely explain exercise limitation. However, in the healthy Fontan patient, limitation is defined by upstream factors which determine systemic ventricular filling. Inadequate preload reserve has been demonstrated to limit cardiac augmentation caused by ionotropic stimulation and it is likely that this mechanism also explains cardiac limitation during exercise. At rest, pulmonary vascular resistance and pressure are low. During exercise, increases in flow mandate an increase in pressure unless resistance can fall proportionately. Substantial reserve in the systemic circulation moderates pressure increases whilst, in the pulmonary circulation, there is evidence that the capacity for further vasodilation is limited. In a normal biventricular circulation, this results in greater pressure and work demands for the RV during exercise. However, in the Fontan patient, there is no RV to provide this work demand and hence flow, LV filling and CO are unable to increase normally.

This discussion of Fontan physiology has important clinical implications. Treatment regimens are most likely to be efficacious if they address the part of the circulation which serves as the greatest source of limitation. Classical heart failure regimens have demonstrated poor efficacy in Fontan patients but this may be expected if the systemic circulation is not the primary source of limitation. Selective pulmonary vasodilators target a potential "weak link" in the Fontan circuit. Early results with these agents have offered promise and may prove an important means of improving exercise tolerance.

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Research Article

Physical Activity in Adolescent Females with Type 1 Diabetes

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Objective. We sought to identify amount of physical activity and relationship of physical activity to glycemic control among adolescent females 11 to 19 years of age with type 1 diabetes mellitus (T1DM). We also sought to evaluate associations of age and ethnicity with physical activity levels. *Research Design and Methods*. Adolescent females ages 11–19 years ($n = 203$) were recruited during their outpatient diabetes appointment. Physical activity was obtained by self-report and was categorized as the number of days subjects had accumulated 60 minutes of moderate-to-vigorous physical activity during the past 7 days and for a typical week. *Results*. Girls reported being physically active for at least 60 minutes per day on 2.7 ± 2.3 days in the last week, and on 3.1 ± 2.2 days in a typical week. A greater number of physically active days in a typical week were associated with lower A1c ($P = .049$) in linear regression analysis. *Conclusion*. Adolescent females with T1DM report exercising for at least 60 minutes about 3 days per week. It is particularly important that adolescent girls with T1DM be encouraged to exercise since a greater number of physically active days per week is associated with better glycemic control.

1. Introduction

The benefit of physical activity in type 1 diabetes (TIDM) was appreciated well before the more recent improvement and advances in diabetes treatment introduced by the Diabetes Control and Complications Trial (DCCT) [1–3]. Physical exercise in adolescents with TIDM is associated with improved lipid levels and lipoprotein (a) [4]. It has also been found to have a positive effect on blood glucose control by improving insulin sensitivity, stimulating muscle glucose uptake, and subsequently leading to decreased insulin requirements [5, 6]. Other studies have found that not only is there an improvement in insulin sensitivity but that Physical Working Capacity, a measure of aerobic fitness, is also found to be improved with increased energy expenditure in adolescents with TIDM [7]. The long-term benefits of exercise also include a reduced risk of coronary artery disease and stroke [8]. Thus, routine physical exercise is integral in helping to prevent chronic diseases in all children, including those with diabetes.

There are not only physical but also emotional benefits to routine physical exercise [9]. In a study by Wiesinger, 23 otherwise healthy patients with history of TIDM underwent a 4-month exercise study and were found to have both improved metabolic control and also Health Related Quality of Life, a measure of daily functioning and general well being [10]. Other studies have also found that physical activity is associated with a reduction in the symptoms of depression and anxiety [11] and with an improvement in self-esteem [12]. Physical activity is therefore important in helping to foster growth and development during childhood.

However, recent data on the amount of physical activity among adolescent females with TIDM and its association with glycemic control are limited and often conflicting. Some studies have shown that improved A1c is associated with increased physical activity in women [13], but others have not found an association [14–16]. The few studies that have looked at physical activity in adolescent females are concerning in that they have found that there is a tendency toward less physical activity [15–17] and increased prevalence of obesity among adolescent females with TIDM [18]. Thus, it is important to better understand if adolescent females with TIDM are also at increased risk for less physical activity and to better understand the relationship between physical activity and glycemic control.

The aim of the present study is to investigate the relationship of physical activity to glycemic control in large group of adolescent females ages 11 to 19 years of age with TIDM. In addition, we aim to evaluate associations of age and ethnicity with physical activity levels, and to see what proportion of adolescent girls with T1DM are currently meeting the recommended guidelines for exercise.

2. Materials and Methods

Subjects were recruited from individuals with T1DM who receive their care at the Barbara Davis Center for Childhood Diabetes. We enrolled females of all ethnicities, defined by the standard 2000 US census questionnaire between the ages of 11 and 19 years of age, and those who had at least one menstrual period were included in the analysis. Subjects with any renal, respiratory, or cardiac disease and any other chronic disease besides TIDM were excluded from the study. Subjects with a preexisting diagnosis of Hashimoto's thyroiditis were included if their initial diagnosis was made by close surveillance and if they had a longstanding history of being clinically and biochemically euthyroid. A total of 234 subjects were enrolled in the study. 15 subjects were excluded because they were 20–24 years of age. Complete data on age at T1DM diagnosis and level of physical activity were available for 203 females with T1DM between the ages of 11 and 19 years of age. Since subjects were randomly recruited during their routine visit, they well represented the adolescent females with TIDM at the BDC. Subjects were randomly approached to partake in the study based on there age and female gender. The study took place between November 2008 and May 2009. Study approval was obtained from the institutional review board at the University of Colorado Denver and participants provided written informed consent and assent, if appropriate, at enrollment.

2.1. Data Collection. The clinical diabetes type assigned by the health care provider was obtained from the medical records and categorized as T1DM if the provider assignment was autoimmune TIDM or idiopathic TIDM [19]. Blood pressure, pulse, height, weight, and A1c were measured at the study visit. For measurement of HbA1c the DCA 2000 manufactured by Bayer was used. The reference value for healthy persons is 4–6%. Blood pressure and pulse were measured in the resting sitting position using 4200 Vital Check equipment. Weight was measured in kg using the Detecto scale. Height was in centimeters by use of Holtain Limited Stadiometer. BMI was calculated as kg/m^2, and BMI z score was determined using age and sex specific BMI percentiles from the Centers for Disease Control and Prevention (CDC). Physical examination was performed by a study investigator. Subjects were asked to fill out four short medical history questionnaires. (1) Screening Demographic Questionnaire, (2) Physical Activity Questionnaire, (3) Menstrual Cycle Questionnaire, and (4) Insulin Record Questionnaire.

The Screening/Demographic Questionnaire asked study participants if they were of Spanish or Hispanic origin or descent. They were also asked which ethnicity they considered themselves to be using the standard 2000 US census questionnaire. In the present study we used a validated questionnaire entitled PACE + (Patient-Centered Assessment and Counseling for Exercise Plus Nutrition) Adolescent Physical Activity Measure survey [20]. Physical activity was obtained by self-report and was categorized as the number of days subjects had accumulated 60 minutes of moderate to vigorous physical activity during the past 7 days and for a typical week and consisted of two questions. Moderate physical activity was defined as "usually makes you breathe hard or feel tired some of the time" and examples were provided: brisk walking, weight lifting, and yard work. Vigorous physical activity was defined as "usually makes you breathe hard or feel tired most of the time" examples were provided: jogging, soccer, and "aggressive" skateboarding. The first question stated "Over the last 7 days on how many days were you physically active for a total of at least 60 minutes per day? The second question stated "Over a typical or usual week, on how many days are you physically active for a total of at lease 60 minutes per day? Both questions had 7 answer choices ranging from 0 days to 7 days per week [20].

Age of the first menstrual period and menstrual cycle pattern and length was obtained by self-report using a questionnaire adapted from the National Health and Nutrition Examination Survey reproductive health questionnaire. The Insulin Record Questionnaire included the number of blood glucose checks the patient performs per day, insulin regimen, and doses. Insulin dose was analyzed as average units of insulin used on a typical day per kilogram of weight per day.

2.2. Definitions. The 2005 physical activity recommendations by the CDC states that school-age youth should participate daily in 60 minutes or more of moderate to vigorous physical activity that is developmentally appropriate, enjoyable, and involves a variety of activities [21], and the American Diabetes Association (ADA) [22] adheres to the CDC recommendations. The American Academy of Pediatrics (AAP) has similar recommendations and encourages children and adolescents to be physically active for at least 60 minutes per day, which does not need to be acquired in a continuous fashion but rather may be accumulated by using smaller increments. Events should be of moderate intensity and include a wide variety of activities as part of sports, recreation, transportation, chores, work, planned exercise, and school-based PE classes [23].

3. Results

Complete data on age at T1DM diagnosis and level of physical activity were available for 203 females with T1DM between the ages of 11 and 19 years. There were 23 subjects with stable, treated hypothyroidism included in the analysis. Characteristics of the study participants are shown in Table 1. The average number of days that subjects reported being physically active for at least 60 minutes per day over the last week was 2.6 ± 2.3 (mean ± SD) days, and for a typical week was 3.1 ± 2.2 days.

Table 1: Characteristics of study participants.

	Total participants ($N = 203$)	Non-Hispanic White ($N = 172$)	Hispanic ($N = 31$)
Age at visit (years)	15.5 ± 2.6	15.5 ± 2.8	15.7 ± 1.8
Duration of diabetes (years)	6.3 ± 4.7	6.4 ± 4.8	6.0 ± 4.1
A1c (%)	9.3 ± 1.9	9.2 ± 1.9	9.8 ± 1.9
Insulin dose (units/kg body weight/day)	0.98 ± 0.34	0.95 ± 0.32	1.1 ± 0.42
BMI (kg/m^2)	23.3 ± 3.7	23.2 ± 3.5	24.0 ± 4.5
BMI z score	0.41 ± 0.83	0.37 ± 0.81	0.64 ± 0.85
Blood Pressure			
Systolic (mm Hg)	112 ± 14	111 ± 15	114 ± 9
Diastolic (mm Hg)	66 ± 9	66 ± 9	67 ± 9
Resting Pulse	83.5 ± 13.0	83.6 ± 13.1	84.3 ± 12.5
Total Physical activity			
(Number of days over the last week that the subject was physically active for at least 60 minutes per day)	2.6 ± 2.3	2.9 ± 2.3	1.9 ± 2.0*
Typical Physical activity			
(In a typical week the number of days that they are physically active for at least 60 minutes per day)	3.1 ± 2.2	3.3 ± 2.1	2.3 ± 2.09*
Met physical activity guidelines (%[12])	4.7%	5.3%	2.5%

*$P < .05$ for NHW versus Hispanic.

Days of physical activity of at least 60 minutes duration in the past week (OR = 0.98 [0.86–1.11], $P = .73$) and typical number of days of physical activity of at least 60 minutes duration (OR = 0.99 [0.85–1.11], $P = .85$) were not associated with irregular periods. However, a greater number of physically active days in a typical week were associated with lower A1c ($P = .049$) in linear regression analysis.

3.1. Age. Level of physical activity was also evaluated by two subgroups: 11–15 years and 16–19 years. As shown in Table 2, adolescent females in the 16–19 year age range reported significantly fewer physically active days in a typical week and in the previous week than girls in the 11–15 year age range. In linear regression analysis adjusted for race/ethnicity and Tanner stage, the number of physically active days in a typical week remained significantly lower in the 16–19 year age group (LS mean 2.7) compared to the 11–15 year age group (LS mean 3.9, $P = .0002$).

3.2. Race/Ethnicity. Level of physical activity by race/ethnicity is shown in Table 1. Females of Hispanic origin in comparison to non-Hispanic white (NHW) reported fewer physically active days in a typical week (2.3 ± 2.1 versus 3.3 ± 2.1 $P = .015$ and in the last week (1.90 ± 2.0 versus 2.9 ± 2.3 $P = .031$). In multivariate linear regression analysis the typical number of physically active days per week was significantly greater in NHW girls (least square mean ± SE = 3.66 ± 0.28 days) than in Hispanic girls (least square mean ± SE = 2.64 ± 0.46 days, $P = .014$), adjusting for age group and Tanner stage.

3.3. ADA Recommendations. Only 10 out of 213 adolescent females (4.7%) met the recommended 60 minutes of physical activity 7 days per week. In a typical week, 35% of adolescent females reported engaging in at least 60 minutes of physical activity 5 or more days per week, while 30% engaged in 1 day or less of physical activity lasting at least 60 minutes. Those with the highest physical activity (5 or more days per week)

Table 2: Level of physical activity by age group.

	Ages 11–15 years ($n = 97$)	Ages 16–19 years ($n = 116$)
Age at visit (years)	13.5 ± 2.7	17.1 ± 1.0[a]
Duration of diabetes (years)	5.0 ± 4.6	7.4 ± 4.4[a]
A1c (%)	9.3 ± 1.9	9.2 ± 1.9
Insulin dose (units/kg body weight/day)	1.04 ± 0.34	0.92 ± 0.34[a]
BMI (kg/m^2) BMI z score	0.48 ± 0.84	0.34 ± 0.82
Blood Pressure		
Systolic (mm Hg)	109 ± 8	114 ± 10[a]
Diastolic (mm Hg)	64 ± 8	68 ± 10
Pulse	84 ± 12.2	83 ± 13.7
Total Physical activity		
(Number of days over the last week that the subject was physically active for at least 60 minutes per day)	3.0 ± 2.2	2.3 ± 2.24[a]
Typical Physical activity		
(In a typical week the number of days that they are physically active for at least 60 minutes per day)	3.6 ± 2.1	2.7 ± 2.2[a]

[a]P-value <.05 compared to 12–15 year age group.

compared to the least active (1 or fewer days per week) were younger (mean age 15.1 ± 1.8 versus 16.2 ± 2.5 years, $P = .007$), had better glycemic control (mean A1c 8.9 ± 1.7 versus 9.6 ± 2.1, $P = .026$), a lower BMI (22.7 ± 3.7 versus 24.3 ± 3.9, $P = .019$), and lower systolic blood pressure (110 ± 16 versus 116 ± 10, $P = .012$), and diastolic blood pressure (64.3 ± 8.6 versus 68.5 ± 9.8, $P = .009$).

4. Discussion

The present study is the largest to date to examine level of physical activity among an unselected group of adolescents and young adults (ages 11 through 24 years) with TIDM studied when they presented for their routine diabetes clinic appointment. The results of this study indicate that adolescent females with T1DM are typically engaged in at least 60 minutes of moderate to vigorous physical activity about 3 days per week, which is similar to results found in other studies [24]. The reported frequency of physical activity in the present study falls short of meeting the guidelines of the AAP [23], the ADA [22], and the CDC [21], which recommend that children engage in at least 60 minutes of physical activity per day.

As expected, we found a correlation between the number of physically active days and A1c, in agreement with findings in some previous studies [13]. This is of important clinical significance since the DCCT [3] and other studies [25] have demonstrated conclusively that improved glycemic control, as assessed by A1c, markedly reduces the development of and progression of microvascular complications of diabetes such as retinopathy, neuropathy, and nephropathy. However, it should also be noted that other studies have not found an association between physical activity and HbA1c [14–16].

We also found that Hispanic females with TIDM were overall less physically active than NHW adolescents with TIDM. These results are similar to other studies that have found that regardless of TIDM status, Hispanic girls tend to be less physically active than their NHW counterparts [26]. This might partly be attributable to lower socioeconomic status among Hispanic females which has been found to be associated with increased risk for a sedentary lifestyle [24].

More frequent weekly physical activity was reported among girls 11–15 years of age with significantly less frequent physical activity reported by girls between 16–19 years of age. Our results are similar to other studies that have also found physical activity to decline and sedentary behavior to become more common during adolescence [27]. Pate et al. specifically examined change in participation in activities during adolescence in girls and found that vigorous physical activity declined from 45.4% in 8th grade to 34.1% in 12th grade. Interestingly, the probability of participating in several forms of vigorous physical activity in 12th grade was strongly associated with participation in those activities in 8th grade [28]. Thus, encouragement of physical activity in those with T1DM at a young age might be important in helping to establish maintenance of physical activity during adolescence and beyond.

Why are not adolescent females with TIDM more physically active? One study has found that the fear of hypoglycemia was the strongest barrier to regular physical activity [29]. This fear could partly be due to the mismanagement of diabetes during times of exercise. In fact, one study that looked at adolescents with TIDM found that only fifty percent of the patients reported monitoring blood glucose levels during exercise, and only 32% changed insulin dose according to blood glucose levels. Also, hypoglycemic episodes (37.7%) were more frequently reported than hyperglycemic episodes [30]. Thus, the complexities of diabetes surveillance and fear of hypoglycemia during exercise can become a unique challenge to those with TIDM.

It is also important that health care providers are familiar with ADA guidelines of physical activity. The ADA recommends that blood glucose monitoring should be done before and at the termination of exercise and at hourly intervals during episodes of prolonged strenuous activity. Fifteen grams of carbohydrates may be administered as a readily absorbed sugar if blood glucose levels are <100 mg/dL during the period of exercise [22]. The DirecNet study group has also found that discontinuing basal insulin during exercise is an effective strategy in those using insulin pumps for reducing hypoglycemia [31]. In addition, they have also found that overnight hypoglycemia after exercise is common in children with TIDM and recommend modifying diabetes management following afternoon exercise to reduce the risk of hypoglycemia [32]. Thus, adolescents with TIDM should be involved in comprehensive teaching programs for self-management of diabetes [33] and should be aware that the existing guidelines are useful, but the exact adjustments of insulin dose must be made on an individual basis [34] with the help of their health care provider.

There were some limitations to our study. First, the participants were predominantly of NHW and Hispanic race/ethnicity, and so we were not able to provide reliable estimates of level of physical activity in other racial/ethnic groups. Also, we did not have a nondiabetic control group to compare physical activity. In addition, there is also the potential for recall bias with the use of self-reported questionnaires. Also, level of energy expenditure is multifactorial and often cannot be well captured by use of a questionnaire [35]. However, similar physical activity questionnaires to the one used in this study have also been found to be valid, reliable, and suitable to use for the purpose of data collection in child and adolescent populations [36]. Further, more frequent reported physical activity was significantly associated with a lower resting pulse and diastolic blood pressure, suggesting that expected physiologic changes were present in association with reported levels of activity.

In conclusion, adolescent females with TIDM report exercising at least 60 minutes a day on 3 days out of a typical week. Only 5% of our subjects met the international recommendations of 60 minutes of moderate-to-vigorous activity per day. Health care providers need to continually encourage adolescent females with T1DM to exercise, and barriers to physical activity need to be reduced, with special attention to Hispanic adolescents and those between 16–19 years of age. Thus, increased physical activity is associated with improved glycemic control in adolescents with TIDM which can ultimately lead to decreased micro- and macrovascular complications of diabetes.

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Clinical Study

Exercise Stress Testing in Children with Metabolic or Neuromuscular Disorders

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The role of exercise as a diagnostic or therapeutic tool in patients with a metabolic disease (MD) or neuromuscular disorder (NMD) is relatively underresearched. In this paper we describe the metabolic profiles during exercise in 13 children (9 boys, 4 girls, age 5–15 yrs) with a diagnosed MD or NMD. Graded cardiopulmonary exercise tests and/or a 90-min prolonged submaximal exercise test were performed. During exercise, respiratory gas-exchange and heart rate were monitored; blood and urine samples were collected for biochemical analysis at set time points. Several characteristics in our patient group were observed, which reflected the differences in pathophysiology of the various disorders. Metabolic profiles during exercises CPET and PXT seem helpful in the evaluation of patients with a MD or NMD.

1. Introduction

Metabolic diseases (MDs) and Neuromuscular disorders (NMDs) comprise a large heterogeneous group of diseases, that directly (via intrinsic muscle pathology or defective metabolic pathways) or indirectly (via nerve pathology), impair muscle function and result in exercise intolerance.

Although the value of exercise tests in patients with MD/NMD has been acknowledged for several decades [1–3], the role of exercise stress tests as a diagnostic or evaluative tool in children and adults with MD/NMD is relatively underresearched. Moreover, exercise stress tests are not standard for most centers to be performed in clinical care [4–7]. In this paper, we provide two standardized exercise tests with preliminary metabolic profiles in children with a diagnosed MD/NMD for this purpose.

Exercise stress tests in patients with a metabolic disorder involved in ATP synthesis show a clear specific metabolic profile during exercise [4]. These metabolic profiles can be useful as a reference for identifying patients for a possible MD or NMD.

Therefore, the aim of the current study was to describe the metabolic profiles during exercise in children with a diagnosed NMD or MD. This information might be helpful for clinicians in the diagnosis and follow-up of patients with these disorders.

2. Methods

2.1. Subjects. In this retrospective chart review, patients with an established diagnosis involving general ATP synthesis or a dystrophinopathy, who were referred for exercise stress testing to the Departments of Metabolic Diseases and Child Development and Exercise Center, University Medical Center Utrecht, the Netherlands, were included.

Table 1: Cardiopulmonary measurements of patients during the CPET.

Patient	Diagnosis	Determination of diagnosis	Age (years)	Sex	Weight (kg)	BMI (Z-score)	HR_{peak} (beats/min)	RER_{peak}	VO_{2peak} (L/min) (Z-score)	VO_{2peak} /kg (mL/min/kg) (Z-score)
1	GSD-1a	Mutation R570X en delta F327	11.9	M	40	19.3 (0.88)	205	1.16	1.99 (−0.04)	49.7 (−0.42)
2	GSD-III	Debranching enzyme deficiency in leucocytes	11.9	F	39	19.6 (0.71)	182	0.92*	1.45 (−1.5)	37.1 (−1.5)
3	GSD-7	Phosphofructokinase deficiency in muscle	12.9	M	32	13.1 (−3.7)	184	1.0	1.78 (−3.55)	34.6 (−3.24)
4	MCAD	MCAD deficiency in leucocytes homozygous Lys329Glu mutation	5.4	F	28	19.4 (1.98)	134	0.92*	0.55 (−3.5)	19.5 (−4.2)
5	MCAD	MCAD deficiency in leucocytes	11.4	F	42	18.9 (0.59)	NA	NA	NA	NA
6	SCAD	SCAD deficiency in leucocytes and fibroblasts; mutation	7.0	M	25	14.6 (0.70)	173	1.05	1.00 (−0.86)	40.1 (−1.9)
7	MADD	MADD deficiency in fibroblasts	10.2	M	33	16.1 (−0.23)	195	1.25	1.33 (−1.1)	40.4 (−1.8)
8	MADD	MADD deficiency in fibroblasts	8.6	M	25	14.1 (−1.35)	180	1.21	1.29 (0.09)	51.5 (−0.26)
9	2-Methylacetoacetyl-CoA-thiolase deficiency	2-Methylacetoacetyl-CoA-thiolase deficiency in fibroblasts	8.7	M	30	15.5 (−0.32)	179	1.20	1.30 (−0.69)	43.5 (−1.4)
10	Mitochondrial respiratory chain myopathy	Diminished ATP production in fresh muscle biopsy	9.7	M	34	16.9 (0.30)	152	1.39	0.63 (−3.6)	18.5 (−5.0)
11	M. Becker dystrophinopathy	Duplication exon 24-29 dystrophin gene	10.4	M	25	12.4 (−3.6)	NA	NA	NA	NA
12	M. Becker dystrophinopathy	Duplication exon 24-29 dystrophin gene	14.8	M	57	18.6 (−0.22)	202	1.26	1.57 (1.7)	62.6 (2.7)
13	Hypokalemic episodic paralysis	Arg1239His mutation in CACNA1S-gene	13.8	F	62	24.5 (1.63)	218	1.25	1.20 (−2.0)	19.4 (−4.0)

Abbreviations: BMI: Body Mass Index, HR_{peak}: peak heart rate, VO_{2peak}: peak O_2 uptake, RER_{peak}: peak respiratory exchange ratio, *: significantly different from normal, NA: not assessed.

Thirteen patients (9 ♂, 4 ♀, age 5–15 years) with an established diagnoses were studied in detail. Diagnoses were Glycogen Storage Disease (GSD) type 1a (1x), GSD type 3 (1x), GSD type 7 (1x), Medium-Chain Acyl CoA dehydrogenase deficiency (MCAD (2x)), Short-Chain Acyl CoA dehydrogenase deficiency (SCAD (1x)), Multiple Acyl CoA dehydrogenase deficiency (MADD (2x)), ketothiolase deficiency (1x), mitochondrial myopathy (1x), Hypokalemic episodic paralysis (1x), and dystrophinopathy (Becker Muscular Dystrophy (BMD) (2x).

2.2. Exercise Tests. Two exercise stress tests, respectively, a cardiopulmonary exercise test (CPET) and a prolonged exercise ergometry test (PXT) were performed following a standardized protocol [8]. Blood samples were taken, immediately before and directly after the CPET and PXT, and analyzed for lactate, creatine kinase (CK), ammonia, acylcarnitines, and organic acid. Urine samples were collected up to three hours after the exercise test and further analyzed for creatinine, organic acid, amino acid, tetraglucose, purine, and pyrimidine [8].

A CPET (to determine the peak oxygen uptake [VO_{2peak}] and peak workload [W_{peak}]) and a submaximal PXT (90 minutes at 30% of W_{peak}) were performed in the morning. After a light breakfast, the patients performed a symptom-limited CPET on a bicycle ergometer. Workload was increased in constant increments of 10, 15, or 20 watts every minute, depending on the patients' length [9] and was in some conditions adjusted for the physical condition of the patient. This protocol was continued

Table 2: Biochemical measurements of patients before and after the CPET.

Patient	Lactate (mmol/L)		CK (U/L)		Ammonia (mmol/L)	
	Before	After	Before	After	Before	After
1	3.5*	10.3	NA	NA	5	4*
2	2.2	1.6	540*	597*	NA	NA
3	0.8	2.4	246*	273*	61*	337*
7	1.3	7.3	125	146	NA	NA
8	1.3	6.0	79	89	NA	NA
9	1.5	4.3	116	121	17	12
10	3.1*	6.9	85	100	8	6*
12	1.5	13*	577*	773*	34*	54
Normal values Mean (range)	1.56 (0.7–2.3)	7.0 (3.2–11.4)	104 (45–192)	123 (51–234)	18 (9–23)	42 (10–94)

Legend: NA: not assessed, *: significantly different from normal.

until the patient stopped due to volitional exhaustion, despite strong verbal encouragement. During the tests, all subjects breathed through a facemask (Hans Rudolph Inc., Kansas City, MO), connected to a calibrated respiratory gas analysis system (Oxygen Champion/Pro, Care Fusion, Houten, The Netherlands). This system measured breath-by-breath minute ventilation (VE), oxygen uptake (VO_2), and respiratory exchange ratio ($RER = VCO_2/VO_2$) using conventional equations. During the maximal exercise test, heart rate (HR) was measured continuously by a bipolar electrocardiogram. Peak HR (HR_{peak}), VO_{2peak}, VO_{2peak}/kg, and peak RER were taken as the average values over the last 30 seconds of the test.

A PXT was performed one week after the maximal exercise test to prevent interference from the previous test. The PXT consisted of a 90-minute cycling at a constant work rate of 30% W_{peak}, as described previously [8].

2.3. Blood and Urine Sampling and Analysis. Blood samples were obtained from an indwelling catheter inserted into a vein of the dorsum of the hand. Five milliliters of blood from each sample was placed in lithium-heparin tube, except for determination of FFA and ammonia; respectively, normal blood (without Li-heparin) and EDTA (another anticoagulant) blood was used for the analysis [8]. After taking the blood, the tubes were stored in ice and brought to the laboratory.

Blood taken before and after the CPET was analyzed for lactate, creatine kinase (CK), ammonia, acylcarnitines, and organic acid. Urine samples taken before and after the CPET, were analyzed for creatinine, organic acid, amino acid, and tetraglucose, until three hours after the exercise test.

During the PXT, blood samples were taken at regular time intervals ($t = 0$, 30, 60, 75, 90, 105, and 120 minutes after the start of the exercise). Concentrations of glucose, lactate, CK, free fatty acids (FFA), ammonia, 3-OH-butyric acid and 3-keto-butyric acid, acylcarnitines, and organic acid were determined. Before and up to three hours after exercise, urine samples were obtained and analyzed for creatinine, organic acid, amino acid, and tetraglucose.

Glucose, lactate, CK, and ammonia were determined with a Beckman Coulter DxC chemical analysis machine (Fullerton, USA). Enzymatic method was used for determination of FFA, 3-ketobutyric acid, and 3-OH-butyric acid. After lipoprotein lipase hydrolyzed triglyceride into fat acids and glycerol, free glycerol was measured colorimetrically.

Organic acid concentration in urine and plasma was determined by gas chromatography-mass spectrometry as their trimethylsilyl derivates (Hewlett Packard 5890 series II gas chromatograph linked to a HP 5989B MS-Engine mass spectrometer (Hewlett Packard, Avondale, PA)). The coefficients of variation for the various measured organic acids varied between 10%–15%. Analysis of acylcarnitine in plasma as their butyl esters was performed by electrospray tandem mass spectrometry (ESI-MS-MS; Micromass Quattro Ultima, Micromass Ltd., UK) equipped with an Alliance HPLC system (Waters, Milford, MA, USA). Also for these analyses the coefficients of variation for the determined acylcarnitines were 10%–15%. Analysis of amino acids in plasma and urine was done with amino acid analyzer (ion-exchange chromatography-ninhydrin).

3. Results

3.1. CPET. As expected, patients with a MD/NMD showed abnormal results on the CPET (Tables 1 and 2). Patient 2 (GSD-3) stopped the CPET because of myalgia in the lower limbs, compared to reference values for healthy children [10, 11], the patients with GSD-3, MCAD, SCAD, and mitochondrial myopathy (patients 4, 6, and 10, resp.) had a significantly reduced HR_{peak}. RER_{peak} was significantly lower in the patient with GSD-3 (patient 2) and also in the patient with MCAD (patient 4) and surprisingly increased to 1.0 in the patient with GSD-7 (patient 3). VO_{2peak} and VO_{2peak}/kg were significantly lower in the patients 3, 4, 10, and 13. These were patients with GSD-7,

Table 3: Biochemical measurements of patients during the PXT test.

Subject	Time (min)	Glucose (mmol/L)	Lactate (mmol/L)	FFA (mmol/L)	3-Keto-B (mmol/L)	3-OH-B (mmol/L)	CK (U/L)	Ammonia (μmol/L)
1	0	4.9	4.3*	0.51	0.14	0.0	116	
	30	4.4	4.6*	0.52	0.13	0.02	115	
	60	5.7*	2.8*	0.489	0.12	0.02	119	
	75	5.6	3.1*	0.536	0.12	0.02	119	
	90	6.7*	2.9*	0.559	0.12	0.02	121	
	15 after	7.4*	4.1*	0.792	0.13	0.04	121	
	30 after	7.5*	4.9*	0.666	0.12	0.04	118	
3	0	5.5	1.8	0.08	0.0	0.0	166	22
	30	5.9	1.2	0.14	0.0	0.0	181*	
	60	5.8*	0.8	0.23	0.0	0.0	186*	
	75	6.9*	1.2	0.36	0.09	0.04	187	275*
	15 after	6.9	2.3	0.25	0.0	0.03	183*	
	30 after		2.0	0.26	0.0	0.0	184*	144*
6	0	4.6	3.2*	0.268	0.12	0.0	48	
	30	4.6	1.3	0.302	0.1	0.0	46	
	60	4.4	1.4	0.444	0.12	0.0	48	
	15 after	4.6	1.1	0.503	0.13	0.03		
	30 after	4.7	0.9	0.528	0.13	0.03	51	
7	0	7.1	1.1	0.76	0.07	0.09	103	
	30	5.6	1.2	0.28	0.0	0.0		
	60	4.9	1.0	0.49	0.0	0.0	98	
	75	4.8	1.3	0.88	0.05	0.05	105	
	90	5.5	1.1	1.03	0.10	0.12	119	
	30 after	4.8	1.0	0.93	0.15	0.26	117	
8	0	5.2	2.0	0.15	0.0	0.0	58	
	30	4.6	0.9	0.31	0.0	0.0		
	60	4.3	0.9	0.62	0.07	0.04	80	
	75	4.4	1.0	0.91			78	
	30 after	4.5	1.2	1.34	0.14	0.24	78	
9	0	6.4	1.4	0.22	0.09	0.03	90	14
	30	4.9	1.4	0.18	0.0	0.0	93	
	60	4.7	1.3	0.21	0.0	0.0	89	
	75	4.4	1.1	0.42	0.0	0.0	99	22
	90	4.9	1.1	0.64	0.11	0.11	91	
	15 after	4.8	0.8	0.69	0.13	0.18	92	
	30 after	4.6	1.0	0.55	0.14	0.2	92	14
10	0	4.0	2.4*	0.20	0.11	0.10*	138	20
	30	3.7*	8.6*	0.21	0.11	0.11*	156	
	60	3.5*	9.6*	0.31	0.14	0.13	151	
	75	3.6*	9.5*	0.49	0.16	0.16	156	20
	90	3.6*	9.7*	0.71	0.16	0.18	157	
	15 after	4.1	7.0*	0.72	0.113	0.29	145	
	30 after	4.0	4.7*	0.73	0.18	0.29	146	
11	0	5.9	1.4	0.41	0.0	0.0	5020*	7.0
	30	4.8	1.4	0.19	0.0	0.0	4975*	
	15 after	5.3	1.4	0.57	0.0	0.0	5036*	
	30 after	5.2	1.3	0.5	0.0	0.0		18

Table 3: Continued.

Subject	Time (min)	Glucose (mmol/L)	Lactate (mmol/L)	FFA (mmol/L)	3-Keto-B (mmol/L)	3-OH-B (mmol/L)	CK (U/L)	Ammonia (μmol/L)
12	0	5.1	1.1	0.15	0.0	0.0	695*	33*
	30	5.3	1.2	0.08	0.0	0.0	776*	
	60	5	1.2	0.11	0.0	0.0	774*	
	75	5.1	1.4	0.16*	0.0	0.0	771*	51*
	90	5.0	1.7	0.23	0.0	0.0	766*	
	15 after	5.1	1.1	0.76	0.0	0.0	755*	

Legend: FFA: free fatty acids, 3-keto-B: 3-ketobutaric acid, 3-OH-B: 3-hydroxybutaric acid, *: significantly different from normal.

MCAD, mitochondrial myopathy, and Hypokalemic episodic paralysis, respectively.

A remarkably high VO_{2peak}/kg was observed in one of the patients with BMD (patient 12).

The patients with GSD-1a and mitochondrial myopathy (patient 1 and 10, resp.) had significantly increased lactate concentrations at rest. Patient 2, with GSD-3, had an increased CK values at rest and after exercise. The 2 patients with BMD (patients 11 and 12) showed persistently highly elevated CK levels. One patient (patient 13) showed mildly elevated CK.

3.2. PXT. Biochemical profiles of the MD/NMD patients during the PXT varied with the disorder (Table 3). Two patients, one with GSD-1a and the other with mitochondrial myopathy (resp., patient 1 and 10), showed significantly increased concentrations of blood lactate at all time points. The patient, with GSD-7 had significantly increased ammonia concentrations with no rise in lactate during exercise.

During and after exercise, the CK value of the patient with GSD-7 (patient 3) was significantly increased as well as in the 2 patients with BMD (patients 11 and 12).

Acylcarnitines C6, C8, C10, C12, and C14:1 were all increased in two patients with MADD (patients 7 and 8) in rest as well as during exercise. The patient with ketothiolase deficiency (patient 9) had increased C5:1 and C5-OH acylcarnitine during rest and exercise, as well as several increased organic acids in the urine. In the patient with mitochondrial myopathy (patient 10), C5 carnitine was increased in the urine during and after exercise. In the patient with SCAD (patient 6), there was no C4 carnitine found. In all other MD/NMD patients, no altered acylcarnitines, carnitines, for organic acids concentrations could be observed in plasma or urine (data not shown).

4. Discussion

The purpose of this study was to describe metabolic profiles during exercise using CPET and PXT including extensive blood and urine analyses in children with a diagnosed MD/NMD. This information might be helpful for clinicians in the diagnosis and follow-up of these disorders. Because of the heterogeneity of the disorders, there was a large variation in the CPET and PXT results between patients. These differences reflect the different pathophysiology of the various disorders (e.g., defects in different metabolic pathways) and heterogeneity within disorders.

Metabolic profiling might be helpful in the further workup towards a diagnosis. For example, a low rise in lactate after CPET is suggestive for a GSD, and a very high increase in lactate, combined with a very low VO_{2peak}, might be suggestive for a mitochondrial myopathy. Further studies should develop an algorithm for the interpretation of exercise data in MD/NMD patients, comparable to the interpretative algorithms for cardiac and pulmonary limitations during exercise [12, 13].

The diagnostic yield of exercise stress testing in children with unexplained exercise intolerance seems relatively low. Among 29 patients referred for exercise intolerance of unknown origin, only 3 patients could be diagnosed with a MD/NMD: 2 patients with a Becker Muscular Dystrophinopathy and one patient with a hypokalemic episodic paralysis. However, many of these patients have undergone extensive medical screening before they were referred for exercise testing. Ten percent is therefore a reasonable yield. It is our opinion that the expense of exercise testing including extensive blood and urine analyses is justified because it could be useful for guiding the diagnostic workup and can differentiate between patients with medically unexplained exercise intolerance and patients with a MD/NMD. In patients with a MD involved in ATP synthesis, only during certain periods of metabolic stress (e.g., exercise, fasting, or illness), abnormal quantities of metabolites in blood and urine can be found, and symptoms are present. These defects can only be indentified using standardized tests. The current paper provides two standardized exercise tests with preliminary metabolic profiles for this purpose.

Furthermore, several of the tested MD/NMD patients (patients 3, 7, 8, and 10) were referred for exercise testing to assess their exercise capacity for physical activity recommendations. Based on their exercise results, an advice regarding appropriate levels of physical activity was provided. Sufficient amounts of physical activity are necessary for an optimal physical, psychosocial, and emotional development in children [14].

In addition, for patient 12, we gave an exercise restriction based on the findings. This patient was a talented cyclist with a very high VO_{2peak} for his age. However, during several races he developed myoglobinuria, and he had quite high resting values of CK. A muscle biopsy in the workup after the tests revealed a duplication in exon 24-29 of the dystrophin gene, and the diagnosis of BMD was made. Based on these results, the boy was advised to stop high-level cycling because of the increased risk of renal failure due to myoglobinuria.

One of the limitations of this clinical report is the small and heterogeneous population. This reflects the rarity of the disorders. Therefore, multicentred studies are needed to increase the sample size for each of the disorders. Further, it is important that these profiles are established in children as not all metabolic profiles seen in adults are valid in children. For example, a recent study showed that the well-known second-wind phenomenon in patients with McArdle's disease (GSD5), which is considered as a diagnostic feature of this disease [15], was not observed in children with McArdle's disease [16].

5. Conclusion

In this paper we describe the metabolic profiles during exercise in 13 children with a diagnosed MD/NMD. Metabolic profiles during exercise were of assistance in diagnosing 3 patients with rare presentations of MD/NMDs. In addition, exercise stress testing was helpful for the prescription of appropriate levels of physical activity.

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Review Article

Exercise Testing and Prescription in Patients with Congenital Heart Disease

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The present paper provides a review of the literature regarding exercise testing, exercise capacity, and the role of exercise training in patients with congenital heart disease (CHD). Different measures of exercise capacity are discussed, including both simple and more advanced exercise parameters. Different groups of patients, including shunt lesions, pulmonary valvar stenosis, patients after completion of Fontan circulation, and patients with pulmonary arterial hypertension are discussed separately in more detail. It has been underscored that an active lifestyle, taking exercise limitations and potential risks of exercise into account is of utmost importance. Increased exercise capacity in these patients is furthermore correlated with an improvement of objective and subjective quality of life.

1. Introduction

In the present era most patients (85%) with congenital heart disease (CHD) reach adulthood [1]. It has therefore become of utmost importance to maintain a good quality of life and physical fitness for these patients. Many studies have established a moderate to good correlation between quality of life and exercise capacity [2, 3]. There are, however, many factors that impede exercise capacity in patients with CHD. They usually perform less physical activities as compared to normal controls [4], know little about their own possibilities [5], and largely overestimate their exercise capacity [6]. In addition, overprotection from the environment results in further reductions in physical activity [7].

We therefore reviewed the literature regarding the assessment of exercise capacity, using both simple and more advanced methods in patients with CHD, the exercise capacity of patients with CHD, and possibilities of exercising without considerable risks.

2. Exercise Testing

Exercise testing is a valuable tool in the management of pediatric patients with heart disease. It can be used to help determine the need for medical or surgical interventions and can be used to determine the efficacy of these interventions [8–10]. Measurement of exercise capacity and other physiological responses provides objective information about the functional status of heart, lungs, and peripheral muscles. This information can be of value in making clinical decisions resulting in a reduced use of hospital facilities, and improved functional capacity and quality of life. A list of indications for exercise testing is provided in Table 1.

Although emergencies are rare in pediatric exercise testing [9], staff should be familiar with emergency maneuvers and the criteria when an exercise test should be terminated (Table 2). Technical aspects of exercise testing are beyond the scope of this paper and can be found in the comprehensive article by Paridon et al. [12].

3. Cardiopulmonary Responses to Exercise

During graded exercise testing, many variables can be measured. The simplest measures are the assessment of heart rate (HR) and work rate or endurance time. The measurement of HR during exercise is simple and inexpensive and provides important information about the cardiovascular system.

Table 1: Indications for exercise testing in children.

(1) Assesses physical capacity for recreational, athletic and occupational recommendations
(2) Evaluates specific pathophysiologic characteristics
(a) provides indications for surgery, therapy, or additional tests
(b) evaluates functional postoperative success
(c) diagnoses disease
(3) Assesses adequacy of therapy
(4) Assesses risk for future complications in existing disease
(5) Instills confidence in child and parents
(6) Motivates child for further exercise or weight loss

Modified after Bar-Or [11].

During exercise, HR increases and the highest obtained HR is defined as the HR_{peak}. In healthy children HR_{peak} is typically about 200 ± 10 for treadmill testing and 195 ± 10 for cycle ergometer testing [9]. After cessation of exercise HR returns to the baseline. This HR recovery is believed to be mainly influenced by vagal autonomic activity, Body Mass Index, and aerobic capacity [14]. Most studies demonstrate a more rapid decline in HR after cessation of exercise in younger children [14, 15]. Studies that determined stroke volume (SV) show that children have a smaller SV during maximal exercise compared to adults. Up to moderate submaximal exercise SV increases, but further increase in cardiac output (CO) during increasing exercise intensity is in children regulated by an increase in HR [9]. This means that beyond moderate intensity exercise (approximately 40% of VO_{2peak}) a reduced increase in HR will result in reduced CO and, although partially compensated by a larger arteriovenous oxygen difference, a reduction in peak oxygen uptake [16].

When a respiratory gas analysis system is available, ventilation (VE), oxygen uptake (VO_2), and carbon dioxide production (VCO_2) can be measured continuously. Peak oxygen uptake (VO_{2peak}) is the traditional gold-standard of aerobic capacity and is a widely used parameter. This VO_{2peak} is determined by the maximal rate of the oxygen transport from lungs to muscle [16], and may be limited by SV, HR, or tissue extraction. Normal values for VO_{2peak} for children and adolescents are recently published by ten Harkel et al. [17].

Ventilatory anaerobic threshold (VAT) is another important parameter of exercise capacity. It is defined as the point at which minute ventilation increases disproportionally relative to VO_2, usually occurring at 50–70% of VO_{2peak} [17]. VAT reflects the point at which anaerobic metabolism starts to increase since oxygen supply cannot keep up with the increasing metabolic requirements of exercising muscles [16].

There are several exercise physiological differences between children and adults which will not be reviewed here in detail. In short, during growth, children show a more marked increase in anaerobic metabolism than aerobic metabolism as they move through adolescence [18]. When children perform an increase in exercise work rate, the increase in VO_2 to a new steady state (oxygen uptake kinetics) is much faster as in adults, and may be due to a more efficient oxygen delivery system, a greater relative capacity for oxygen utilization at the muscle, or both [18].

One of the more recently proposed parameters that can be obtained during exercise testing is the VE/VCO_2 slope. The VE/VCO_2 slope is obtained by linear regression analysis of ventilation (VE) to carbon dioxide exhalation (VCO_2) as can be continuously measured during exercise during the complete exercise period. This value reflects ventilatory drive.

Another contemporary parameter that can be obtained during exercise testing is the Oxygen Uptake Efficiency Slope (OUES). In an attempt to develop an objective and effort-independent measure of cardiorespiratory fitness in children with CHD, the OUES was introduced [19]. The OUES represents the rate of increase of VO_2 in response to a given VE during incremental exercise, indicating how effectively oxygen is extracted and taken into the body [20]. OUES is determined from the linear relation of VO_2 (y-axis) versus the logarithm of VE (x-axis) during exercise, that is, $VO_2 = a \log_{10} VE + b$, where a is the OUES and b is the intercept [20]. The logarithmic transformation of VE is aimed at linearizing the otherwise curvilinear relation of VO_2 versus VE, so making the OUES theoretically independent of the patient-achieved effort level. The OUES is a parameter that indicates the status of both systemic and pulmonary perfusion, and which explains the high correlation with VO_{2peak} [19, 21, 22].

4. Exercise Capacity in Patients with CHD

Currently, most patients with CHD will survive into adulthood. However, residual defects or problems occur relatively often. Although most patients will report normal exercise capacity, a reduction in exercise capacity may be the first sign of changes in cardiac function. Many cardiopulmonary variables may contribute to a reduced exercise capacity, including systolic and diastolic ventricular dysfunction, sinus node dysfunction, and changes in cardiac autonomic nervous activity. Many studies have investigated the exercise capacity by means of formal exercise testing in these patients [2, 23–31]. This is important, since many patients grossly overestimate their physical capabilities. There is only a poor association between the measured exercise capacity (e.g., peak oxygen uptake) and the self-reported physical functioning [6].

Many studies investigating both children and adult patients with CHD found a lower than normal HR_{peak} [2, 23–31]. This lower HR_{peak} is usually defined as chronotropic incompetence when less than 80% of the predicted HR_{peak} is reached during graded exercise testing, although giving sufficient effort [23]. Factors influencing HR_{peak} in children are intrinsic sinus node dysfunction, and impaired sympathetic cardiac autonomic nervous activity [32] as well as the mode of exercise (e.g., running provides a somewhat higher HR_{peak} compared to cycling). HR dynamics seem to be more influenced by the surgeries itself than by the resultant hemodynamic abnormalities [33]. Cardiac

Table 2: Criteria for terminating exercise testing in children with CHD.

(1) Clinical	Symptoms as chest pain, severe headache, dizziness, chills, sustained nausea, inappropriate dyspnoea
	Signs as sustained pallor, clammy skin, disorientation, inappropriate affect
	Patient requests termination of the test
(2) Electrocardiography	Failure of heart rate to increase with exercise, and extreme fatigue, dizziness, or other symptoms suggestive of insufficient cardiac output
	Premature ventricular contractions (PVC) with increasing frequency
	Ventricular tachycardia (run of >3 PVCs)
	Supraventricular tachycardia
	ST segmental depression, or elevation, of more than 3 mm
	Triggering of atrioventricular (AV) block (2nd degree AV-block type Mobitz or 3rd degree AV block) by exercise
	Triggering of QTc lengthening >500 ms
(3) Blood pressure	Excessive levels (age dependent)—systolic blood pressure >250 mmHg, diastolic blood pressure >125 mmHg
	Progressive fall in systolic blood pressure with increasing work rate
(4) Progressive fall in oxygen saturation to <90% or a 10-point drop from resting saturation in a symptomatic patient	

Modified from Connuck [8] and Paridon et al. [12].

Table 3: Recommendations for competitive sport participation.

The following congenital heart defects can participate in all sports without restrictions
ASD (closed or small unoperated) and patent foramen ovale (Except Scuba diving in PFO)
VSD (closed or small unoperated)
AVSD (Only mild AV insufficiency; no significant subaortic stenosis or arrhythmia)
Partial or complete anomalous pulmonary venous connection (No significant pulmonary or systemic venous obstruction, no pulmonary hypertension or exercise-induced arrhythmia)
Persistent ductus arteriosus (operated) (6 months post closure and no residual pulmonary hypertension)
Mild pulmonary stenosis (normal RV, normal ECG)
Mild aortic stenosis (With the exception of high static, high dynamic) (Mean gradient <21 mmHg; no history of arrhythmias, no dizziness, syncope, or angina pectoris)
Transposition of the great arteries after arterial switch (With the exception of high static, high dynamic) (No or only mild neo-aortic insufficiency; no significant pulmonary stenosis; no signs of ischemia or arrhythmia on exercise ECG)

Modified from Pelliccia et al. [13].

denervation and damage to the sinus node or its blood supply, leading to sinus node dysfunction may play a role [33, 34]. Although parasympathetic nervous activity may improve after surgery, sympathetic reinnervation remains uncertain [35]. Chronotropic incompetence is also related to lower exercise capacity and increased levels of NT-pro-BNP in adults [36]. Disorders mostly related to chronotropic incompetence were single ventricle physiology (52%), Mustard operation for transposition of the great arteries (46%), and aortic coarctation (38%) [31], and Eisenmenger patients (90%) [23]. HR reserve is defined as the difference between resting HR and HR_{peak}, and is physiologically important since, as described above, beyond moderate intensity exercise a further increase in CO can only be established by a further increase in HR. A decrease in HR reserve has been related to a higher mortality risk in adult CHD patients [23]. A slower HR recovery after cessation of exercise indicates impaired vagal autonomic activity and is usually related to a lower exercise capacity. This makes the HR recovery a good indication of vagal tone, and it has been shown to be a useful marker for evaluating patient outcomes in cardiac rehabilitation in children with CHD [2]. Cardiac autonomic nervous activity has also been shown to be useful in stratifying mild and severe heart failure in pediatric heart failure patients, due to dilated cardiomyopathy or as a result of CHD [33]. In some patients, for example, patients after Fontan operation, cardiac autonomic nervous activity has been found to be reduced even without signs of heart failure [37]. The role of the autonomic nervous system has been studied extensively by Ohuchi et al. [32, 38]. They found in

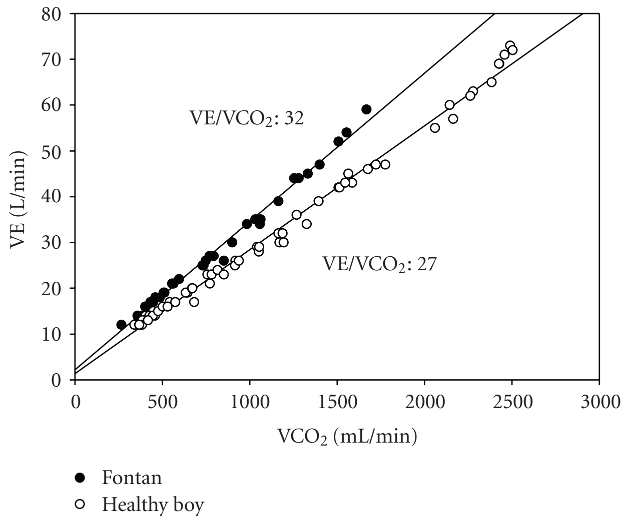

Figure 1: The VE/VCO_2 slope in a 13 year old boy with a Fontan circulation and in a 13-year old healthy boy.

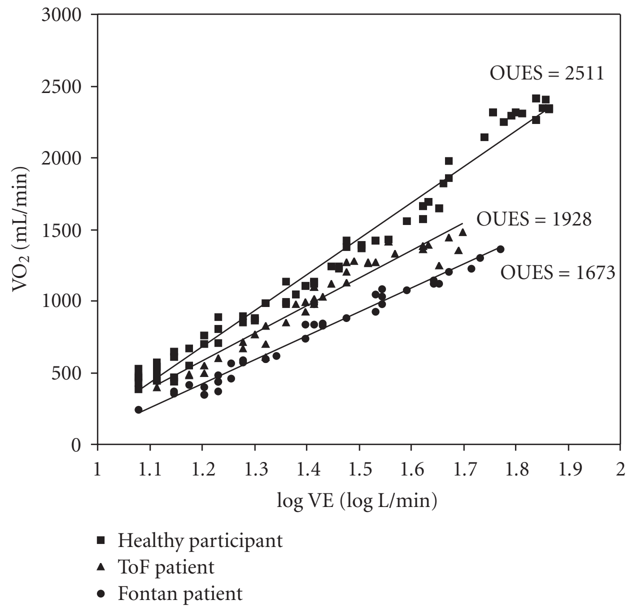

Figure 2: The OUES during an exercise test in a healthy 13-year-old boy, in a sex- and age-matched patient with tetralogy of Fallot, and in a sex- and age-matched Fontan patient.

patients with CHD a blunted HR increase during exercise, and delayed early HR recovery. These were independently associated with impaired sympathetic and parasympathetic cardiac autonomic nervous activity [38].

When blood pressure is taken into account, maximal circulatory power can be defined as the peak work rate (Watt) × highest mean blood pressure that is reached during peak exercise. The use of circulatory power as a prognostic marker is independent from VO_{2peak} and chronotropic incompetence [24]. Peak circulatory power incorporates the blood pressure response to exercise, and it has been shown that the pressure-generating ability of the heart is a prognostic marker in heart failure patients [39]. In adult patients with CHD this circulatory power is reduced as well [24].

The VO_{2peak} is reduced in most adult patients with CHD, ranging from a minor reduction in coarctation patients, to severely impaired VO_{2peak} in Eisenmenger patients [40]. The VE/VCO_2 is increased in many CHD patient groups, being the worst in cyanotic patients with or without pulmonary hypertension [41]. However, some VSD patients may show normal values of VE/VCO_2 [42]. The increase in VE/VCO_2 slope indicates that in patients with CHD the ventilation is increased to constrain the fall in arterial pH. In Fontan patients an increased VE/VCO_2 may be related to intracardiac and intrapulmonary shunting, and may be further impaired by increased pulmonary vascular resistance and low CO [41]. An example of a young Fontan patient is shown in Figure 1. In adults with cyanotic heart disease the VE/VCO_2 slope was most closely related to symptoms of exercise incapacity [43].

Pulmonary function may play an additional role in exercise limitations in some CHD patients [44]. Reductions in forced expiratory volume in 1 second, forced vital capacity, and 1-minute ventilatory volume have all been found in adults with CHD [45]. As lesions associated with increased pulmonary blood flow may result in pulmonary vascular obstructive disease, lesions with reduced pulmonary blood flow may result in hypoplasia of lung arteries and a reduced number of alveoli [45]. In operated patients thoracotomies and cardiopulmonary bypass can lead to increased lung stiffness and thereby further decrease pulmonary function [46].

The oxygen uptake efficiency slope (OUES) has been used in adult heart failure patients, and has shown to be a reliable parameter, that can be obtained during submaximal exercise with a good correlation to VO_{2peak} [47]. Exercise training of these patients results in an improved OUES, also with a good correlation to the changes in VO_{2peak} [48]. However, OUES in adult cyanotic Fontan patients changes over the entire exercise duration, which makes it unable to predict maximal exercise capacity in these patients [49]. However, we observed a linear OUES values in pediatric Fontan patients with or without cyanosis as well as in pediatric tetralogy of Fallot patients (Bongers et al. submitted for publication). In addition we found significant differences between healthy children and children with CHD (with Fontan and tetralogy of Fallot repair). In Figure 2 an example of the OUES is provided.

5. Exercise Capacity in Specific Lesions

Shunt Lesions. In patients with a left to right shunt pulmonary blood flow (Qp) is increased in excess of systemic blood flow (Qs). A significant shunt is usually defined as a Qp/Qs ratio >2. The most common lesion with left to right shunting is an atrial septal defect (ASD), and there are significant differences in exercise capacity between patients before and after ASD closure. This contrasts to the unchanged exercise performance in VSD patients, although only small unoperated VSDs are included in the study of Binkhorst et al. [50]. They studied a small group of children who had undergone surgical closure of their VSD ($N = 13$) or had a small unoperated VSD ($N = 14$). Exercise capacity was not significantly different from controls. Although VSD patients had a lower participation in sports, and HR_{peak} was somewhat lower in the operated patients, these differences did not result in differences of peak work rate or VO_{2peak} as compared to healthy control subjects [50].

In a large group ($N = 52$) of adults (38.6 ± 15 years) with an ASD with a Qp/Qs of 2.7 ± 0.7, exercise capacity, was severely reduced before surgery [51]. Although surgery led to a significant improvement in exercise capacity as well as a decrease in VE/VCO_2, in patients with preoperative signs of pulmonary hypertension exercise capacity remained below predicted values [51]. Also percutaneous ASD closure in adults led to an improvement in exercise capacity [52]. This increase was irrespective of age at ASD closure, but was absent in patients with a small atrial shunt (Qp/Qs <2). The improvement in VO_{2peak}, and oxygen pulse (VO_{2peak}/HR_{peak}) was correlated with Qp/Qs before closure [53]. It was found that the improvement in VO_{2peak} and oxygen pulse were correlated to an increase in left ventricular ejection fraction and an increase in left ventricular enddiastolic diameter. It was concluded that an increase in both left ventricular SV and CO due to a positive ventricular interaction is the mechanism leading to improvement in VO_{2peak} [53]. In a study of Giardini et al. [54] 29 adults before, 6 and 36 months after transcatheter ASD closure were studied. A significant improvement in exercise capacity beyond 6 months post procedure was found. This was irrespective of age at intervention. The improvement was correlated to Qp/Qs before closure. The improvement was associated to an improvement in cardiac form and function. Those patients who did not reach normal values after 36 months (20%) had a severely reduced (<50% of predicted) VO_{2peak} before closure.

6. Pulmonary Valvar Stenosis

Patients who had surgical repair of an isolated pulmonary valvar stenosis during childhood show excellent long-term survival. Exercise capacity, however, is slightly decreased during long-term (22–33 years) followup as well as HR_{peak} [55]. This decrease is related to the development of pulmonary regurgitation [55]. Also long time after percutaneous balloon valvuloplasty of pulmonary stenosis the development of pulmonary regurgitation is associated with diminished exercise capacity and a lower VO_{2peak} [56]. In a group of children and adults with a variety of underlying CHD and pulmonary stenosis/regurgitation percutaneous pulmonary valve implantation led to an increase in exercise capacity, which was related to a reduction of pulmonary regurgitation [57]. From these studies it has become clear that especially the development of pulmonary regurgitation in former pulmonary stenosis patients has a deleterious effect on exercise capacity.

7. Fontan Circulation

Exercise capacity and cardiorespiratory responses to exercise are significantly reduced in patients who have undergone the Fontan procedure [58]. This appears to be due to the absence of a ventricle in the pulmonary circuit, disadvantageous systemic ventricular power, increased afterload profile, and a limited ventricular reserve capacity in these patients. Several studies have emphasized the ongoing risk for late failure and poor functional outcome. Ventricular filling, which is determined by the pulmonary vascular bed, appears to be a major determinant of the functional result after Fontan repair [59]. These findings have been extensively studied by Robbers-Visser et al. who determined that under dobutamine stress there was an abnormal decrease in end-diastolic volume, and no change in SV [60]. These findings further underscore the fact that in the Fontan patients there is an impaired preload during stress; therefore, CO ($= SV \times HR$) can be increased only by increasing HR [60]. Interestingly, HR_{peak} during exercise is significantly reduced in Fontan patients. In a meta-analysis of 25 studies a mean HR_{peak} of 153 ± 10 beats/min was reported [61]. This low HR_{peak} further compromises increases in CO during exercise in Fontan patients.

Recently, Muller et al. studied 57 patients after Fontan completion (age 8–52 years). Exercise capacity was severely reduced after total cavopulmonary connection (TCPC), corresponding to 60% of reference values [62]. This compares well with the results from 411 children with a Fontan circulation from 7 Pediatric Heart Network centers, who had a VO_{2peak} of 65% of predicted age and gender [63]. Fontan palliation in early childhood results in a higher VO_{2peak} during long-term followup [62]. Regular surveillance of the exercise capacity by spiroergometry is indispensable for the supervision of patients with Fontan haemodynamics [64]. In the study of Muller et al. daily activities of the Fontan patients was within recommended levels in 72% of the patients [62]. Daily activities were especially reduced in older patients and in patients with a lower VO_{2peak} [62]. Another study observed that the activity patterns in Fontan patients were markedly reduced as well. In a study of 147 Fontan patients, 7–18 years old, measured time spent in moderate and vigorous activity was markedly below normal at all ages, and was not significantly related to self-reported activity levels [4]. Lower physical activity levels were significantly related to lower perceived general health [4]. Since most patients with Fontan physiology have some degree of cyanosis, an increased hemoglobin concentration is necessary for adequate oxygen delivery to the tissues. As in other cyanotic lesions it is therefore essential to prevent iron deficiency which is directly related to exercise capacity [65].

8. Pulmonary Hypertension

CHD associated with large aortopulmonary shunt and high pulmonary pressure finally leads to irreversible pulmonary arterial hypertension. This situation carries a high risk of morbidity and mortality. Until recently treatment options were limited to the avoidance and treatment of complications. Patients with pulmonary arterial hypertension (PAH) related to CHD have an extremely low exercise capacity [66–68].

The only options to improve exercise capacity is by reducing the pulmonary arterial hypertension. Bosentan treatment has been proven to induce short- and mid-term clinical, exercise, and haemodynamic improvements in patients with PAH related to CHD [66]. A small but significant improvement in VO_{2peak} was shown from 16.8 ± 1.4 to 18.3 ± 1.4 mL/kg/min [67]. However, objective exercise values appear to slowly return to baseline during longer follow-up periods [68]. The improvement in exercise capacity has been shown to be correlated to an improvement in quality of life and stabilization of exercise capacity.

9. Prognosis of Impaired Exercise Capacity

Although a mildly impaired exercise capacity may not interfere with normal daily life, its relation to prognostic values makes it an important monitoring tool. However, these prognostic markers have as yet only been found in adult CHD patients, while its role during childhood remains as yet speculative. A reduction in peak circulatory power is related to the presence of heart failure symptoms, and is a strong predictor of mortality [24]. Chronotropic incompetence is related to higher NYHA class, and increased NT-Pro-BNP [36], and predicts mortality independently of functional class and VO_{2peak} [23]. A reduction in VO_{2peak} predicts hospitalization and death [40]. Moreover, an abnormal VE/VCO_2 slope is a strong predictor of death in adult patients with CHD [41].

10. Exercise Training in Congenital Heart Disease Patients

Basic Exercise and Guidelines. Children with CHD run the risk of becoming overweight and have low levels of physical activity [69]. A healthy and active lifestyle is as important in these patients as in the general population [70]. Regular physical activity is associated with many health benefits in patients with cardiac disease. Physical exercise and sports activities have an important beneficial effect on cardiorespiratory function. The intensity of exercise training should be adapted to the specific lesion and to the functional result obtained [71]. Advances in treatment have resulted in an increasing population of adults with CHD. Physical activity in these patients appears to convey beneficial effects, especially on health-related quality of life [3].

Many prepubertal children with CHD need no restrictions in their physical activity. Regular exercise at a recommended level can be performed and should be encouraged at all ages in all patients with CHD. Many children as well as adults can attend sports without any restriction [13, 72]. Special concern should be given to those patients with a significant ventricular dysfunction or recent history or risk of arrhythmia [72]. Although most patients show a willingness to participate in exercise, they frequently are uncertain about safety or benefit [73]. More than 50% of the patients show a significant lack of knowledge about appropriate levels of physical activity for their cardiac condition [74]. This may result in the fact that most adult patients fail to achieve national guidelines for physical activity, ranging from 77% in NYHA class I patients to 100% for those who are in NYHA class III and IV [73]. An important contributing factor to the impaired exercise capacity is the hypoactive lifestyle, as often observed in patients with CHD [75]. This frequently results from parental or environmental overprotection [76]. Patients with CHD should be actively encouraged and stimulated to adopt an active lifestyle including appropriate exercise training and sports [70]. General guidelines are provided in Table 3.

In general, children with CHD should be advised to comply with public health recommendations of daily participation in 60 minutes or more of moderate to vigorous physical activity that is developmentally appropriate, enjoyable, and involves a variety of activities. Adults with CHD are advised to perform 30 minutes or more of moderate to vigorous activities on most days of the week.

11. How Effective Is Exercise Training?

Most studies in patients with CHD use an adult-type endurance exercise rehabilitation programme lasting ∼3 months. Usually the training is performed 2-3 times per week, with an intensity between 60–80% of HR_{peak} [77]. After these training interventions an improvement in peak work rate [26, 27] and VO_{2peak} has been found [2, 26, 27]. This improvement persisted during a 6–12 months follow-up period [2, 27]. Also HR recovery during exercise improved [2]. The improvement in exercise capacity appeared to be a result of an increase in the oxygen pulse ($=VO_{2peak}/HR_{peak}$) at peak exercise, while significant changes in HR_{peak} were not observed [26, 27]. Exercise training may also improve respiratory muscle oxygenation in children with CHD [78]. These changes were associated with improvements in self-esteem, behavior, and emotional state [2]. Even a simple physical activity intervention like regular walking is feasible, safe, and significantly increases the exercise capacity of adult patients at all stages of CHD [5]. Also for Fontan patients it is possible to increase exercise capacity by a formal exercise training program [79]. In several studies with relatively small numbers of patients, VO_{2peak} and endurance time duration during exercise testing increased by 10–15%, while HR_{peak} remained unchanged [28, 79]. Even patients with severe chronic PAH can improve significantly in exercise capacity (6-minute walking distance, VAT and VO_{2peak}) after a 15 week training program. In this program both moderate intensity (60–80% of HR_{peak}) endurance exercise as well as low intensity resistance training and respiratory exercises as well were performed [80]. The results from this study show that formal exercise training is beneficial for patients with PAH. However, to our knowledge, no studies are available in pediatric patients with PAH related to CHD.

However, some words of caution are necessary, because there are many limitations in the designs of these studies. In many studies, there was no control group, a large drop-out of subjects and no long-term followup of the program. Future studies should overcome these methodologic shortcomings as well as design a more child-friendly exercise training program to enhance acceptability and enjoyment which will result in an improved adherence to the program and long-term exercise adherence.

12. Conclusion

In this paper, we discussed how exercise capacity can be measured by using only HR and work rate, or with the use of respiratory gas analysis in patients with CHD. In addition, we discussed the exercise capacity of patients with CHD, and possibilities of physical activity and exercise without considerable risks as well as exercise rehabilitation. Specific attention has been paid to a variety of CHD subgroups.

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Clinical Study

Effects of Juvenile Idiopathic Arthritis on Kinematics and Kinetics of the Lower Extremities Call for Consequences in Physical Activities Recommendations

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Juvenile idiopathic arthritis (JIA) patients ($n = 36$) with symmetrical polyarticular joint involvement of the lower extremities and healthy controls ($n = 20$) were compared concerning differences in kinematic, kinetic, and spatio-temporal parameters with 3D gait analysis. The aims of this study were to quantify the differences in gait between JIA patients and healthy controls and to provide data for more detailed sport activities recommendations. JIA-patients showed reduced walking speed and step length, strongly anterior tilted pelvis, reduced maximum hip extension, reduced knee extension during single support phase and reduced plantar flexion in push off. Additionally the roll-off procedure of the foot was slightly decelerated. The reduced push off motion in the ankle was confirmed by lower peaks in ankle moment and power. The gait of JIA-patients can be explained as a crouch-like gait with hyperflexion in hip and knee joints and less plantar flexion in the ankle. A preventive mobility workout would be recommendable to reduce these restrictions in the future. Advisable are sports with emphasis on extension in hip, knee, and ankle plantar flexion.

1. Introduction

Juvenile idiopathic arthritis (JIA) in children and adolescents is a chronic autoinflammatory affection which might occur in any joint [1]. The disease causes pain that may lead to posture and movement modifications and arouses muscular imbalance with reduced range of motion in the affected joints [2]. These processes may lead to malpositioning or compensatory movements that increase the risk for subsequent degenerative joint diseases. In previous studies an inflammation in joints of the lower extremity was associated with changes in the normal gait [3–5].

A method to analyze the human gait is the 3d-gait analysis. At the German Center for Pediatric and Adolescent Rheumatology Garmisch-Partenkirchen, this technique is performed in JIA patients with multiple affected joints in the lower extremities to quantify kinematics and kinetics to individualize and optimize the physio- and sports therapy.

Physical activities are increasingly considered as an important part of treatment for JIA patients. Moreover inactivity is expected as a major factor of substantial negative effects for the musculoskeletal system, the whole body-composition, and the physical ability of JIA patients. The aim of therapy is to retain or regain an adequate level of activity in order to counteract the loss of coordination and fitness in spite of the disease activity.

In therapy of JIA, prevention of joint dysfunction and reeducation of physiological movements are important issues which might be supported by sport activities.

The aim of this study was to compare the gait of JIA patients with normal gait and further to quantify malpositions in the lower extremities and joint restrictions during

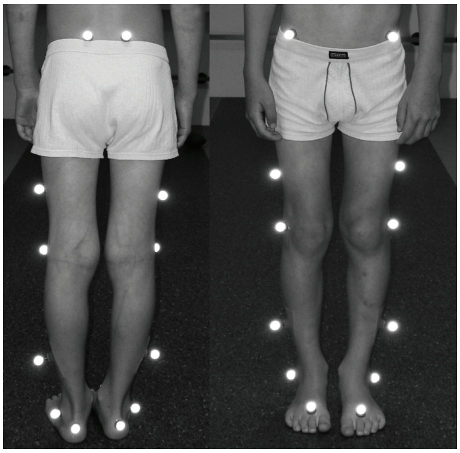

Figure 1: Placement of the Plug-in-Gait Model.

walking condition. These data may lead to recommendations about sport activities.

2. Methods

The study is based on a retrospective analysis of JIA patients admitted in the German Center for Pediatric and Adolescent Rheumatology, Garmisch-Partenkirchen between August 2006 and November 2009. The 3d gait analysis is a part of the routine procedures used to quantify movement restrictions to individualize physiotherapy. Written consent was delivered by the participants or parents (legal guardians) for the anonymous use of these data for scientific purpose.

2.1. Participants. The patient group (JIA-P) ($n = 36$) included children and adolescents, who suffered from JIA with symmetric polyarticular joint involvement with inflammation and/or movement restrictions in both hip, knee and ankle joints (sex: ♀ = 22; ♂ = 14; age: 13.2 ± 4.2 y; weight: 44.0 ± 17.7 kg; height: 1.49 m ± 0.15 m). For comparison a control group (CG) of 20 voluntary, healthy young individuals have been examined (sex: ♀ = 17, ♂ = 3; age: 17.9 ± 6.5 y; weight: 53.8 ± 15.0 kg; height: 1.59 ± 0.13 m).

Comparison of our measured standard values with results from the literature showed only minor deviations [6, 7]. Thus we have used our own CG to minimize the measurement error.

2.2. Data Collection and Processing. Gait analysis is performed in a 9 m long and 3 m wide laboratory which is equipped with a 3d-motion analysis system including six infrared cameras (120 Hz) (Vicon, MX3) and one 3d ground reaction force plate (1080 Hz) (AMTI). The participants were marked in accordance to the Plug-in-Gait Model for the lower extremities [8, 9] with 16 reflecting balls (∅ = 14 mm). This model supports calculation of joint angles, as well as moments and power with inverse dynamics (Figure 1).

As most of our JIA-patients had walking disabilities, we have asked the participants to select a walking speed which was pleasant for them. Each subject completed at least two attempts in order to get accustomed to the measuring situation before the analysis started. For the kinematic evaluation twelve left and right gait cycles were used. The kinetic data consist of three left and right steps of each individual.

The gait was scaled and normalized in separated gait cycles, consisting of a stance and a swing phase of one limb. A gait cycle starts with the initial contact and ends with the next initial contact of the same leg (Figure 2). A t-test for paired samples showed no significant differences within the investigation groups between the right and left side. Therefore the right and left results of each participant were averaged. In addition a clinical joint assessment was done by a physician according to the neutral zero method before 3d-gait analysis. Statistical analyses were made on the basis of arithmetic means (plus standard deviation) focused on the spatio-temporal parameters walking speed, step length, step width, and percentage time of foot off during one gait cycle. Due to the body height variation between the investigation groups, the step length (SL) and walking speed (v) were compared in their absolute value and additionally dimensionless after the scheme of Hof [10, 11] by using the leg length (L_{leg}) and Newton's constant (g):

$$\mathrm{SL}^* = \frac{\mathrm{SL}}{L_{\text{leg}}}, \qquad v^* = \frac{v}{\sqrt{g * L_{\text{leg}}}}. \tag{1}$$

The kinematic parameters of special interest were (i) pelvic tilt, (ii) pelvic obliquity, (iii) pelvic rotation, (iv) hip flexion/extension, (v) hip abduction/adduction, (vi) knee flexion/extension, (vii) ankle joint dorsal/plantar flexion, and (viii) plantar angle in order to describe the roll-off behavior of the foot (Figure 5).

The maximum peak values of kinetic data were calculated in the ankle dorsal flexion moment and in the power that is generated in the ankle (Figure 6). While these data were normalized to the body weight, the ground reaction forces were presented in percent of body weight. The vertical force (Fz) was compared in two peaks Fz_1 (loading response), Fz_3 (terminal stance phase) and in the valley Fz_2 (midstance phase) (Figure 7). The horizontal force in gait direction was analyzed in the maximum of the positive peak Fy_1 (deceleration effect) and in the minimum of the negative peak Fy_2 (acceleration effect) (Figure 7).

Statistical analyses for comparison were performed using the t-test for two independent samples. All analyses have been performed bilaterally. The normal distribution was tested and proven by the kolmogorov-smirnov test for all parameters of interest [12]. The equality of variances was controlled by the Levene test. Statistical significance was determined at the level of $P < .05$. SPSS 18.0 was used for statistics (SPSS Inc. USA).

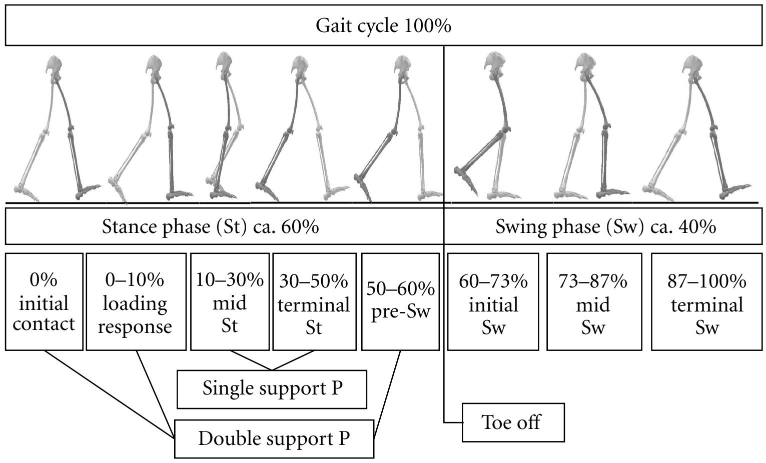

Figure 2: Normal gait cycle with approximated event timings (modified to Perry [6]).

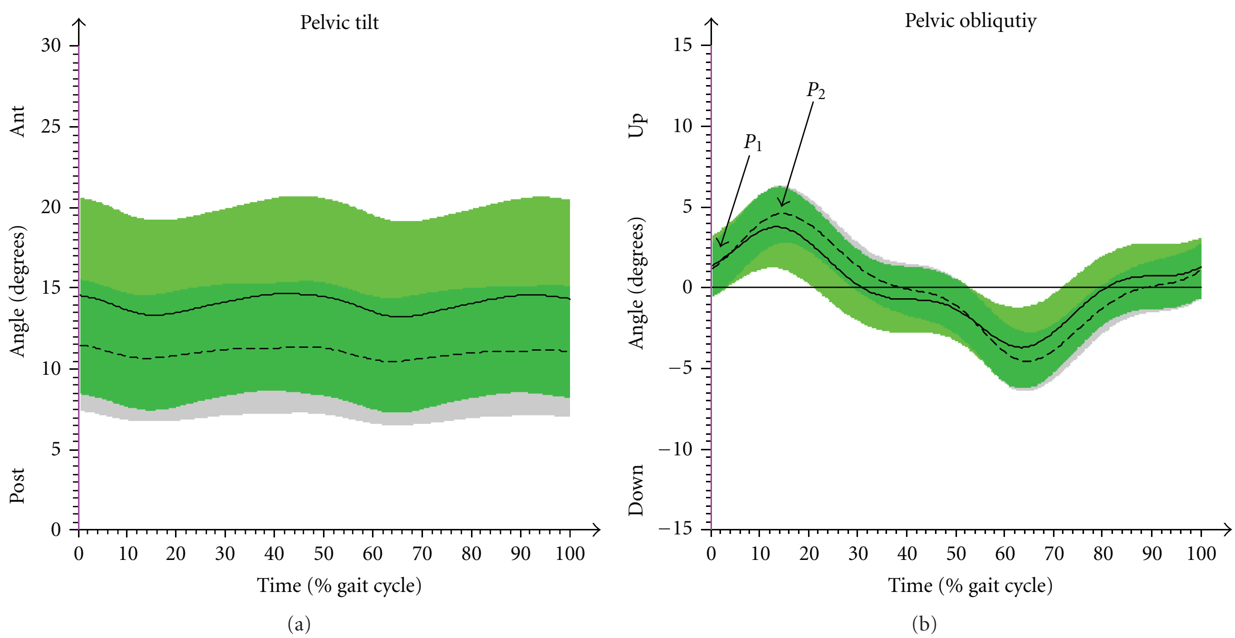

Figure 3: Comparison of angle progression in the pelvic tilt (a) and obliquity (b). CG (arithmetic mean & SD (- - -)); JIA-P (arithmetic mean and SD (—)). P_1 (initial contact) and P_2 (max. increase in loading response) are the points of interest in the pelvic obliquity.

3. Results

Kinematic and spatio-temporal data included all participants of JIA-P and CG. In five individuals (1 JIA-P, 4 CG) ground reaction force data were not available due to invalid contact or technical difficulties. Thus inverse dynamic calculations were possible only in 35 patients and 16 controls. Subsequently the account will focus predominantly on statistically significant differences, and conspicuous results of the joint assessment will be presented.

3.1. Spatio-Temporal Parameters. Comparison of spatio-temporal parameters showed statistically significant differences in the self-chosen walking speed ($P < .001$). JIA-P went with an average speed of 1.06 m/s while CG had chosen 1.32 m/s. Nearly the same statistical significance was seen in the dimensionless comparison of the walking speed ($P < .001$). This decreased velocity in the patient group came along with a smaller step length absolutely ($P < .001$) as well as relative to leg length ($P < .001$). The step width was increased in JIA-P (0.12 m) compared to CG (0.09 m; $P < .01$). The foot off in JIA-P took place after 61.1% of gait cycle while in CG the foot off occurred at 59.9% ($P < .05$) (Table 1).

3.2. Kinematic Results

3.2.1. Pelvis. Patients showed a stronger anterior tilting pelvis than controls ($P < .05$). The pelvic obliquity of JIA-P had a statistically significant smaller range of motion (ROM)

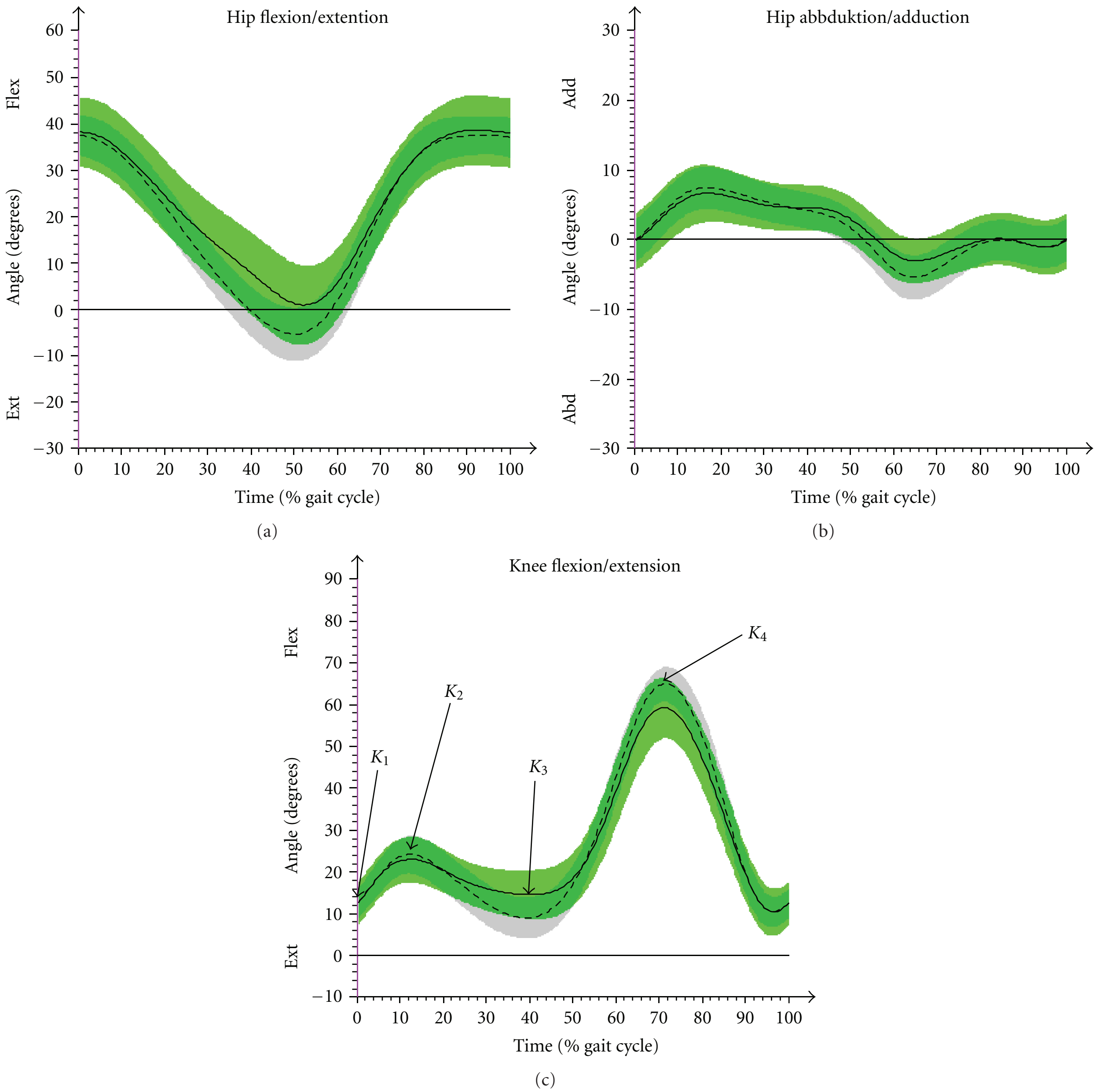

Figure 4: Results of gait analysis of CG (arithmetic mean & SD (- - -)) and JIA-P (arithmetic mean & SD (—)) in hip (a) flexion/extension, (b) abduction/adduction, and knee joint, (c) flexion/extension. K_1 (initial contact), K_2 (max. flex in loading response), K_3 (max. extension in single support phase), and K_4 (max. flexion in swing) are the points of interest in knee joint that were used for statistical analyses.

Table 1: Results of spatio-temporal parameters (* = statistically significant).

		Control group ($n = 20$)	mean (SD)	JIA-Patients ($n = 36$)	mean (SD)	t-Test
Foot Off	[%]	59.9	1.7	61.1	2.3	.049*
Step Length	[m]	.63	.05	.53	.08	.000*
Dimensionless Step Length		.78	.04	.69	.12	.000*
Walking Speed	[m/s]	1.32	.08	1.06	.17	.000*
Dimensionless Walking Speed		.47	.03	.39	.07	.000*
Step Width	[m]	.09	.02	.12	.04	.010*

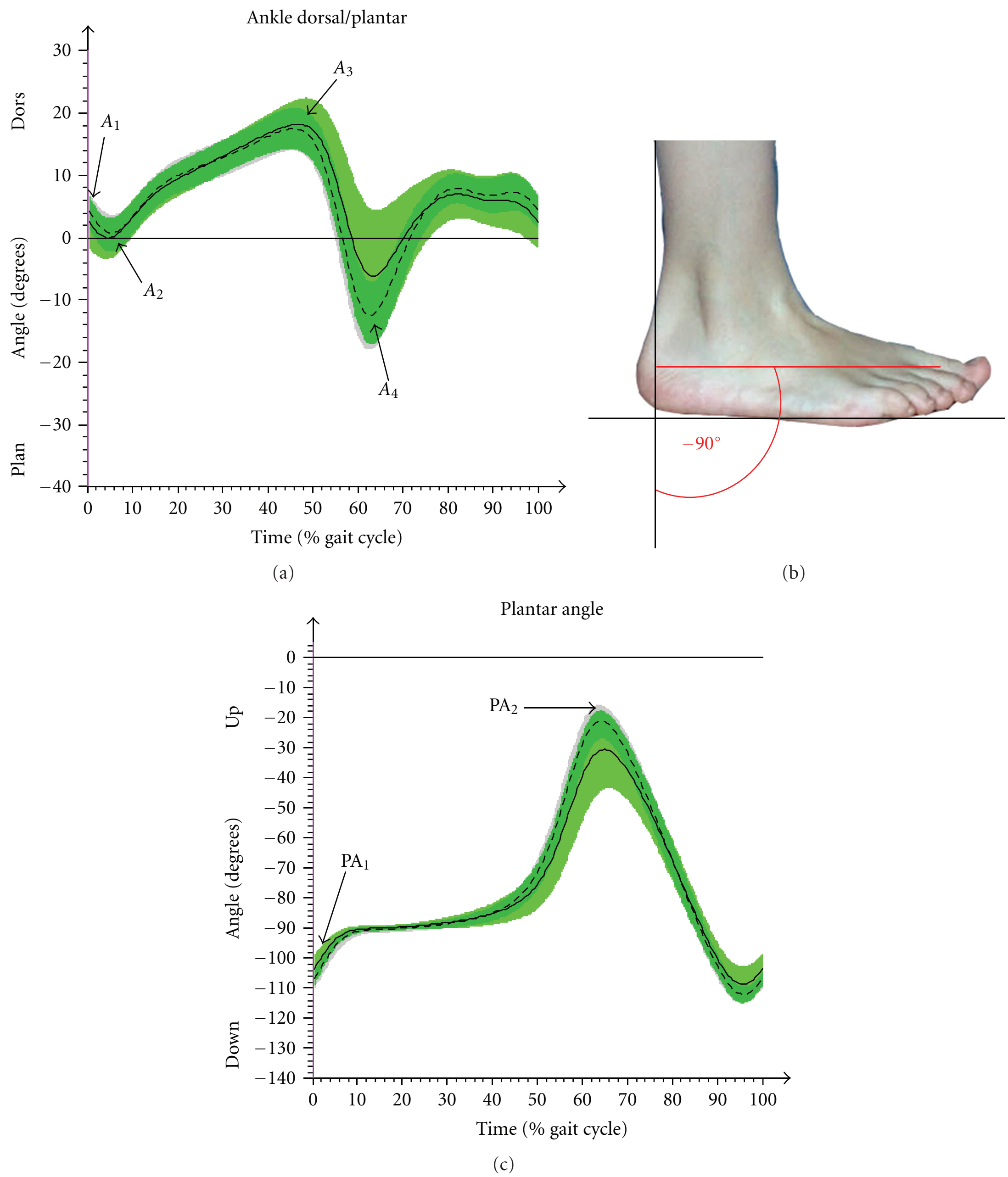

Figure 5: Results of CG (arithmetic mean & SD (- - -)) and JIA-P (arithmetic mean & SD (—)) in time normalized (%) gait cycle in ankle and plantar angle. (a) In ankle (dorsal/plantar flexion), A_1 (initial contact), A_2 (min. value of dorsal flexion in loading response), A_3 (max. dorsal flexion in stance phase), and A_4 (max. plantar flexion while push off or swing) were used for statistical analyses. (b) The plantar angle is the negative angle between the vertical to the ground and the foot longitudinal axis. (c) In plantar angle, PA_1 (initial contact), PA_2 (peak in swing phase), and the percentage of time while the foot is flat on the ground ($-90°$ ($\pm 2°$)) were of interest.

in the contralateral drop of the pelvis from initial contact to maximum height during loading response (Figure 3) ($P < .05$). There were no statistically significant results in the ROM of pelvic rotation (Table 2).

3.2.2. Hip. The maximum ROM during hip flexion and extension during stance phase appeared clearly different ($P < .001$) with JIA-P showing statistically significant lower values compared to CG (Table 2; Figure 4). While hip flexion was similar in both groups JIA-P performed minor hip extension ($P < .01$). The CG had a maximum extension average value of 5.8° while the JIA-P failed to reach full extension by 0.7° (flexion position). This corresponds to the results of the clinical assessment, where 12 of 36 patients showed bilateral hip flexion contractures. The maximum flexion position occurring either during landing phase or at the end of the swing-phase was increased in JIA-P, but

Table 2: Kinematic parameters in pelvis, knee, and ankle Joint (*: statistically significant; NS: not significant).

		Control group ($n = 20$)	Mean (SD)	JIA-Patients ($n = 36$)	Mean (SD)	t-Test
Pelvic Tilt-Average	[°]	10,8	3,9	14,2	5,9	,027*
Pelvic Obliquity (ROM (P_1-P_2))	[°]	3,6	1,2	2,7	1,5	,022*
Pelvic Obliquity ROM	[°]	11,2	5,1	12,4	5,4	NS
Hip Flex/Ext-max. extension	[°]	5,8	5,4	−,7	8,3	,002*
Hip Flex/Ext-max. flexion	[°]	38,2	4,0	39,6	7,4	NS
Hip Flex/Ext-ROM	[°]	44,0	3,3	38,8	5,9	,001*
Hip Abd/Add-max.Abd	[°]	6,0	2,8	4,2	2,0	,009*
Hip Abd/Add-max.Add	[°]	7,8	2,6	7,2	3,0	NS
Hip Abd/Add-ROM	[°]	13,8	3,5	11,4	3,4	,019*
Knee Flex/Ext-K_1	[°]	12,7	3,2	12,4	4,8	NS
Knee Flex/Ext-K_2	[°]	24,6	4,3	23,1	4,9	NS
Knee Flex/Ext-K_3	[°]	8,8	4,4	13,4	4,9	,001*
Knee Flex/Ext-K_4	[°]	65,5	3,0	59,7	6,2	,000*
Knee Flex/Ext (ROM (K_1-K_2))	[°]	12,0	2,3	10,7	3,9	NS
Knee Flex/Ext (ROM (K_2-K_3))	[°]	15,8	3,2	9,7	4,5	,000*
Knee Flex/Ext (ROM (K_3-K_4))	[°]	56,7	3,8	46,4	8,3	,000*
Ankle Dorsi/Plan-A_1	[°]	4,2	2,6	2,6	3,9	NS
Ankle Dorsi/Plan-A_2	[°]	,6	2,8	−,5	3,2	NS
Ankle Dorsi/Plan-A_3	[°]	17,9	2,8	18,9	3,2	NS
Ankle Dorsi/Plan-A_4	[°]	−13,0	4,5	−6,7	10,0	,010*
Ankle Dorsi/Plan-(ROM (A_1-A_2))	[°]	3,6	1,3	3,1	1,8	NS
Ankle Dorsi/Plan-(ROM (A_2-A_3))	[°]	17,4	3,0	19,4	4,0	NS
Ankle Dorsi/Plan-(ROM (A_3-A_4))	[°]	31,0	4,9	25,6	7,9	,008*
Plantar Angle-Initial Contact	[°]	−106,9	2,6	−103,9	4,8	,012*
Plantar Angle-max (swing phase)	[°]	−20,4	4,1	−30,1	11,7	,001*
Foot-Flat (±2°)	[%]	23,7	4,8	27,7	8,0	,045*

however this was not significant. Abduction and adduction were measured as the ROM from neutral position to peak adduction or peak abduction. While no differences were detected in the maximum value of adduction the JIA-P had a lower maximum abduction (JIA-P = 4.2°; CG = 6.0°; $P < .05$). The absolute ROM from peak adduction to peak abduction was decreased in JIA-P ($P < .01$) as well.

3.2.3. Knee. From the initial contact (K_1) to the flexion peak (K_2) there was no significant difference (Table 2). Knee extension at the end of single support phase (K_3) was significantly reduced ($P < .01$). The maximum flexion during swing phase (K_4) was smaller in JIA-P ($P < .001$) (Figure 4). Sixteen JIA-P had a bilateral and three a unilateral restriction in the knee extension with a deficit of at least 5° to neutral position, measured in the clinical examination.

3.2.4. Ankle/Foot. The dorsal flexion of the ankle joint movement throughout the stance phase (A_2-A_3) was increased within JIA-P (+2°) but this was not significant. The following plantar flexion while push off (A_3-A_4) was decreased in JIA-P compared to CG ($P < .01$) (Figure 5). A static motion limitation in plantar flexion (less than 50° plantar flexion) was seen bilaterally in 29 patients by the clinical joint assessment.

The plantar angle (Figure 5) was smaller in JIA-P in the initial contact (PA_1) ($P < .01$), as well as in the peak during swing phase (PA_2) ($P < .001$). The roll off behavior was measured by the time while the foot was parallel to the ground (±2°) in stance phase. JIA-P showed a prolonged phase of foot flat.

3.3. Kinetic Results

3.3.1. Ankle Dorsal Flexion Moment and Power. The maximum peak of kinetic ankle dorsal flexion moment showed smaller values in JIA-P compared to the CG ($P < .001$). The same difference was observed for the maximum ankle power during the push off. Values in JIA-P were significantly decreased ($P < .001$) (Figure 6).

3.3.2. Vertical and Horizontal Ground Reaction Force. The comparison of the three turning points Fz_{1-3} displayed only in Fz_2 a statistically significant difference ($P < .05$) (Table 3; Figure 7). In the horizontal plane the ground reaction force values of JIA-P were decreased in the push off ($P < .001$). Maximum values for the deceleration indicated no differences.

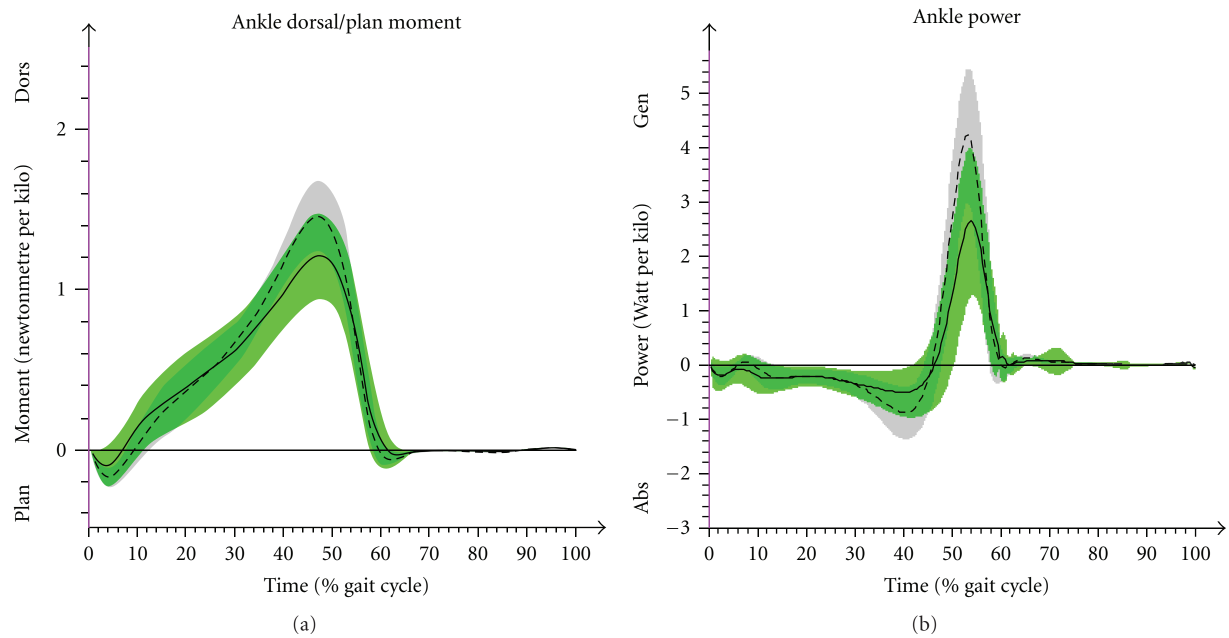

Figure 6: It shows kinetic results of CG (arithmetic mean & SD (- - -)) and JIA-P (arithmetic mean & SD (—)) in time normalized (%) gait cycle of the ankle. (a) Ankle moment (dorsal/plantar flexion). (b) Ankle power.

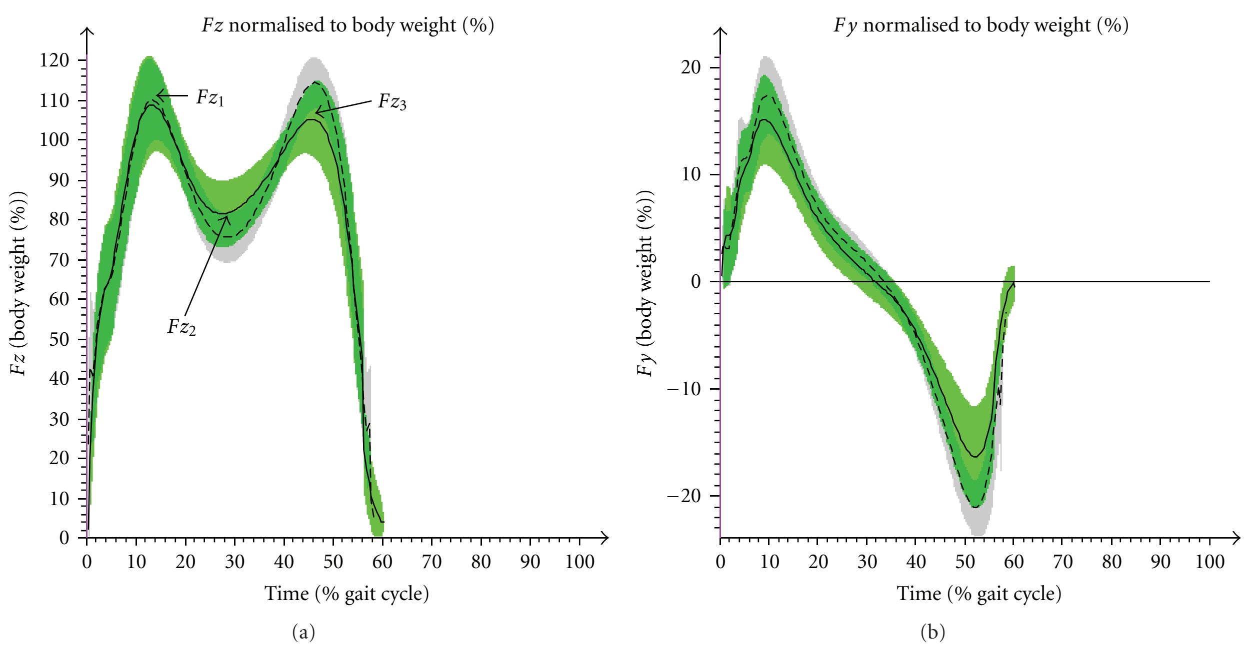

Figure 7: Kinetic results of CG (arithmetic mean & SD (- - -)) and JIA-P (arithmetic mean & SD (—)) in time normalized (%) gait cycle of ground reaction forces (GRF). (a) In the vertical GRF (Fz) the peaks Fz_1, Fz_3 and the value Fz_2 were compared. (b) In the horizontal GRF (Fy) in gait direction the max. peak and the min. peak were used for statistical analyses.

4. Discussion

4.1. Differences between JIA-P and Normal Gait. Comparison of gait parameters between JIA Patients with a polyarticular pattern of joint involvement of the lower extremities and healthy young individuals showed statistically significant differences. First the decreased walking speed of patients may result from pain, movement restrictions, and compensatory movements but as well from insufficient practice. Decrease of the self-selected walking speed in JIA patients has been

Table 3: Kinetic parameters of the Ground Reaction Force (GRF) in vertical plane (z) and horizontal in gait direction (y) as well as the ankle dorsal moment and power (*: statistically significant; NS: not significant).

		Control group ($n = 16$)	Mean (SD)	JIA-Patients ($n = 35$)	Mean (SD)	t-Test
GRF(z) $P1$	[% BWT]	107,0	15,5	110,6	9,7	NS
GRF(z) $P2$	[% BWT]	71,7	9,8	77,4	7,2	,025*
GRF(z) $P3$	[% BWT]	111,8	16,4	106,9	6,9	NS
GRF(y) $P1$	[% BWT]	17,2	3,7	15,8	3,6	NS
GRF(y) $P2$	[% BWT]	−21,3	3,2	−17,2	4,3	,001*
Ankle (max-Dorsi-moment)	[Nm/kg(BWt)]	1,5	,2	1,2	,2	,001*
Ankle (max-Power generation)	[W/kg(BWt)]	4,5	,9	3,0	1,2	,000*

observed in other studies as well. There is a statistically significant negative correlation with pain and progressive movement speed in children with JIA [3, 13]. The decreased walking speed is accompanied by a shorter step length of the JIA-P.

The measured hip extension restriction during single stance phase in JIA-P together with the smaller ROM in the hip (flexion/extension) may be responsible for the shorter step length and slower walking speed [6]. These results fall into place with the clinical examination where one third of the patients had a reduced static hip extension. The increased pelvic tilt may be a compensatory movement of the decreased hip extension as well as the reduced knee extension in single stance phase. Effects of this matter may lead to a higher energy consumption and a reduced leg stability [14].

Götz-Neumann [14] explained the reduced knee extension, that was measured in the JIA-P while single stance phase, as an adaptation to excessive hip flexion during single stance phase or a weak m. gluteus maximus. Furthermore knee pain and hypertonic knee flexors may be responsible for conspicuous reduced knee mobility. Knee joint involvement typically results in muscular imbalance with hypertonia of the hamstring muscles and hypotonia of the m. quadriceps femoris [15, 16]. This leads to a reduced forward progression [6]. The clinical joint assessment revealed knee contractures in 16 patients. But it seems unlikely that this restriction is the reason for the reduced extension during single support phase because the knee extension in initial contact showed normal extension and was equal to the control group.

The decreased maximum knee flexion in swing phase measured in JIA-P may be interpreted as a functionally reduced locomotion and thus be a symptom of knee pain or reduced forward motion of the thigh which is in accordance with the data reported by others [14].

The knee flexion during loading response was found to be in normal ranges and is therefore better than expected from the data of a smaller patient group of JIA patients with minor amount of affected joints that we published before [5].

The ankle joint of JIA-P showed an increased (not significant) dorsal flexion during stance phase. This must be interpreted together with the observation of the extended time duration while the foot stands flat on the ground and the strongly decreased plantar flexion during push off. The timing of foot off appears in JIA-P 1.2% of a gait cycle later than in CG. Although the toe off in our investigation groups appeared within the normal range of a gait cycle, the previous facts suggest a more passive and decelerated roll off behavior in patients. These results are supported by the decreased plantar flexion in JIA-P during gait which was confirmed in 29 patients by clinical assessment.

The special character of the sagittal joint movement in the gait of JIA-P with hyperflexion in hip and knee joints and reduced plantar flexion in the ankle may be described as a crouch-like gait. This can be characterized as typical gait for patients with polyarticular JIA.

The decreased ROM in the contra lateral drop of the pelvis of JIA-P during loading response might be a sign for a compensatory movement. We and others relate this to hip pain [14] and muscle weakness in the m. quadriceps femoris and the gluteal muscles [15]. This motion pattern which was observed in some of the patients corresponds to Duchenne limping. The reduced ROM in pelvic obliquity can be interpreted as stiffness in the pelvis and contributes with a shorter step length and a smaller hip extension (terminal stance phase) to the reduced hip abduction.

Kinetic differences in the lower peaks of ankle joint moments and in ankle power of JIA-P add to a more passive and less dynamic push off compared to controls. This effect also results in the reduced loading of the horizontal ground reaction force (Fy). The vertical force (Fz) divergence between both groups can be explained by the slower walking of patients.

Although the JIA-P represent a homogeneous sample with similar joint manifestations, standard deviations were increased. This suggests that the disease creates very individual patterns of joint disturbances.

4.2. Therapy Recommendations. The results of the 3d-gait analysis gave new and affirmative arguments that help to recommend sport therapy. Additionally the expertise in pathophysiology and treatment of JIA-P with polyarticular joint pattern was also taken into account for the following suggestions [2, 17, 18].

The 3d-gait analysis showed that the patient group suffered from malpositions that can be ascribed to movement restrictions or relieving postures which again can result in further movement restrictions. The main differences compared to controls lay in reduced hip extension, reduced knee extension, and reduced plantar flexion with a passive and decelerated push off of the ankle. Joint restriction goes along with a hypertonic flexor muscle loop and a hypotonic extensor muscle loop. Another study found that the exercise capacity is significantly decreased in a large amount of JIA-P group [19]. Therefore we see that these patients need to practice in different types of physical abilities, mobility, strength, and endurance. It is important that each sector is well balanced. Concerning mobility that means that emphasis must lie on stretching the hypertonic flexor muscle loop but also consider the extensors. To maintain mobility of the pelvic obliquity it seems to be equally important to stretch regularly into hip abduction as well as adduction. Mobility in that region is also important to absorb vertical loadings. Swimming in breaststroke technique could support the functional mobility.

Pain and inflammation reduce the muscle strength for plantar flexion, knee extension and weaken the gluteal muscles [15]. When inflammation subsides, these muscles should be trained. Therefore the strengthening training for the lower limb should focus on the extensor muscle loop and in a lower dose also for the flexor muscle loop [20]. This could counteract against the measured crouch-like gait.

Continuous sports activity will automatically normalize endurance. So this important part of physical ability can be improved indirectly.

Based on the underlying passivity of the ankle joint and the therefore decelerated progression, as well as on the crouch-like gait, the ability to react on unforeseen situations may be considered to be one of the major limiting factors in JIA-P. In this case, functional joint flexibility is as important as lower limb strength and the ability to coordinate it.

As JIA tends to run with phases of relapses and remission, we suggest integrating a preventive mobility workout (PMW) for the entire body very close to the present state of an individual patient. A short daily workout including mobility and strengthening exercises could lead to a better functional outcome of the lower limb. This must be analyzed by a longitudinal intervention study.

In general sport activities with a hard and irregular underground like alpine skiing may cause imbalanced movements which result in high strains on the muscular skeletal system. This means a large training stimulus but with higher risk of injury and a possible worse joint prognoses when starting before remission [21].

Bicycle riding is a smooth motion with low impact and is regarded as an optimum activity for JIA patients. However, the fixed sitting position may produce movement restrictions especially concerning hip extension. Therefore an individualized stretching program should be included also in a gentle sport like bicycle riding.

If arthritis is located at the lower extremities, optimized training programs should take in exercises with smooth motions and low impact. Motion patterns in joints should develop a large ROM that works towards the extension of knee and hip joints. Examples are the diagonal technique of classic style cross-country skiing, swimming (crawl), or Nordic Walking.

5. Conclusion

The results indicate the wide range of disturbances in the mobility of the lower extremities in patients suffering from JIA. 3d-gait analysis has demonstrated to be a powerful tool in quantification of movement abnormalities in patients with JIA. Nearly one third of JIA patients reaching adulthood suffer from limitations in their ability to move [22]. Therefore it is mandatory to enhance the treatment of children with rheumatic diseases especially concerning physio- and sport therapy. Further studies are necessary to provide more detailed data to optimize recommendations for sporting activities.

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Review Article

Exercise Training in Children and Adolescents with Cystic Fibrosis: Theory into Practice

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Physical activity and exercise training play an important role in the clinical management of patients with cystic fibrosis (CF). Exercise training is more common and recognized as an essential part of rehabilitation programmes and overall CF care. Regular exercise training is associated with improved aerobic and anaerobic capacity, higher pulmonary function, and enhanced airway mucus clearance. Furthermore, patients with higher aerobic fitness have an improved survival. Aerobic and anaerobic training may have different effects, while the combination of both have been reported to be beneficial in CF. However, exercise training remains underutilised and not always incorporated into routine CF management. We provide an update on aerobic and anaerobic responses to exercise and general training recommendations in children and adolescents with CF. We propose that an active lifestyle and exercise training are an efficacious part of regular CF patient management.

1. Introduction

Physical activity and exercise training have become increasingly important and widely accepted as part of therapy and rehabilitation programmes in cystic fibrosis (CF) management. Physical activity refers to any body movement produced by the skeletal muscles and occurs in a variety of forms (i.e., free play, exercise, organised sports), resulting in a substantial increase in energy expenditure [1]. Exercise training, however, can be defined as regular participation in vigorous physical activity to improve physical performance or cardiovascular function or muscle strength or any combination of these three [2]. Prior to initiation of any exercise training, detailed exercise testing is recommended, not only to monitor disease progression, but also to detect exercise-induced limitations and therefore to provide the patients with safe training recommendations [3, 4]. Ideally, exercise training should complement current therapies in CF patient healthcare. In previous reports, however, it has emerged that clinicians lack specific recommendations to instruct their patients appropriately [5, 6].

Several studies report beneficial effects of exercise training on cardiopulmonary fitness (CPF) in patients with CF [7–11]. CPF pertains to the functions of both the heart and the pulmonary system, usually expressed as peak oxygen consumption (peak $\dot{V}O_2$), the most reliable and reproducible measure of CPF following maximal exercise testing [12]. Recently, Bradley and Moran examined the effectiveness of exercise training in CF using a systematic Cochrane review [13]. Seven randomised controlled trials with a total number of 231 participants were included, investigating the effects of different types of training (aerobic versus anaerobic training, anaerobic training, aerobic training, and the combination of both). The authors conclude that exercise training is an important part of CF care; however, there are insufficient numbers of studies published to date to document the benefits of exercise training for people with CF. Nevertheless, the authors state that there is no evidence to actively discourage exercise training [13]. In 2009 Wilkes et al. underlined the importance of exercise and habitual physical activity in children with CF [14]. In particular, Wilkes et al. highlighted that education of health care providers and implementing exercise in clinical practice are needed [14].

Regular exercise training may improve pulmonary function, increase aerobic and anaerobic capacity, strengthen ventilatory muscles, and help airway sputum clearance, the latter probably due to enhanced ventilation and vibrations during exercise, leading to mechanical airway clearance [7, 8, 11, 15–19]. Furthermore, it is suspected that moderate intensity exercise blocks the amiloride-sensitive sodium channels of the respiratory epithelium, thus resulting in lower mucus viscosity, simplifying mucus expectoration [20]. Moreover, higher activity levels and peak $\dot{V}O_2$ are positively related to survival in CF [21–23]. Types of training (aerobic versus anaerobic) may have different effects on improvement in exercise tolerance [13], but most training studies so far have focused on endurance training, observing improvements in pulmonary function, peak $\dot{V}O_2$, breathlessness, and quality of life [11, 18, 19, 24]. Exercise training including anaerobic (strength) exercises can improve muscle strength and muscle size, resulting in weight gain [16, 19, 25]. Therefore, a comprehensive training programme should include a variety of sports activities, adapted to the special needs and preferences of each individual. However, the effects of training most likely depend on the training methods, as improvements may only persist with continuous training in the long term. The aim of this paper is to provide a focused update on aerobic and anaerobic responses to exercise and habitual physical activity exclusive to children and adolescents with CF. This paper will help to strengthen the rationale for the initiation of further clinical trials examining the effects of regular exercise on overall health in the paediatric CF population.

2. Method of Review

All relevant studies for this paper were identified using electronic search of Medline and PubMed databases. A bibliography search of all accessed publications was also performed. Key descriptors were cystic fibrosis, training, rehabilitation, aerobic fitness, children, and adolescents. The selection of studies presented in the paper was based upon the agreement by all four authors. We include studies of subjects with CF, independently of their disease severity, and type of exercise training (aerobic training; anaerobic training; combination of aerobic and anaerobic training, as well as inspiratory muscle training).

2.1. Physiological Responses to Exercise in Children and Adolescents with Cystic Fibrosis. Physical activity is a fundamental part of the growth and development of children. Neither any physical activity nor an exercise task can be considered as solely aerobic or anaerobic. The nature of a child's activity requires an interplay of both aerobic and anaerobic metabolism. An update on aerobic and anaerobic performance in children with CF is outlined below.

2.1.1. Aerobic Responses to Exercise. Aerobic exercises include any kind of activities using large muscle groups that can be maintained continuously in a rhythmic manner (e.g., swimming, cycling, or running). Activities with moderate effort can be performed over hours without significant decline in exercise performance (although there is some variation on individuals' physical fitness, energy intake during exercise, etc.). Aerobic capacity of children with CF over a long period of time is less researched, indicating the dearth of data regarding longitudinal assessment of peak $\dot{V}O_2$. Klijn et al. investigated the longitudinal relationship between peak $\dot{V}O_2$, pulmonary function, and body composition in 65 children with mild CF lung disease (10.5 ± 2.9 years of age; forced expiratory volume in 1 s (FEV_1) 92.6 ± 20.5% predicted) over two years. The authors found that longitudinal changes in lung function were associated with functional changes in peak $\dot{V}O_2$ and to a lesser extent with fat free mass (FFM). While FFM is a critical determinant of maximal exercise capacity, FFM may be important for maintaining overall functional capacity and to improve long-term outcome in CF [26, 27]. Peak $\dot{V}O_2$ during maximal exercise is an established prognostic marker in CF [21–23]. In particular, longitudinal data of peak $\dot{V}O_2$ in children with CF indicate a decline in peak $\dot{V}O_2$ over time; however, those with higher peak $\dot{V}O_2$ values have a prolonged survival [23]. In comparison to healthy subjects, children with CF show reduced maximal exercise performance, decreased respiratory function, malnutrition, and physical inactivity as well as intrinsic abnormalities of the skeletal muscle, all likely to be contributing factors [28, 29]. Diminished efficiency of mitochondrial oxidative Adenosine Triphosphate (ATP) synthesis or abnormalities in myofibril mechanics may also affect maximal exercise capacity in CF [26, 30]. It has also been reported that peak $\dot{V}O_2$ and early oxygen consumption ($\dot{V}O_2$) recovery are significantly related in children with chronic lung disease, implying that the greater the aerobic fitness, the faster the rate of recovery following exercise [31]. Hebestreit et al. reported slower $\dot{V}O_2$ kinetics at the onset of exercise in children with CF compared to healthy children, probably due to an impairment in oxygen delivery [32].

CF lung disease is often associated with physical inactivity and deconditioning. Improvements in CPF require individual dosages of training stimuli and vary among individuals. However, the optimal training modes for patients with CF have not yet been identified. It has been demonstrated that the time spent on physical activity in children with CF is similar to that of healthy children, but healthy children spend more time exercising at vigorous intensities [33]. In contrast, Selvadurai et al. observed differences in activity behaviours between prepubertal and pubertal children with CF of different stages of disease severity and their healthy peers using accelerometry and activity diaries. Prepubertal and pubertal children with mild CF lung disease were more active compared to their healthy controls. Interestingly, between prepubertal children with moderate-to-severe CF lung disease and a control group no differences were found. Gender differences occurred between pubertal girls and boys with CF, as girls' habitual physical activity levels were significantly lower. However, compared to healthy controls, pubertal children with moderate to severe CF disease were significantly less active [34]. Gender differences in habitual physical activity levels between healthy girls and boys are well known, not only when comparing to chronically diseased children [35, 36].

Several studies investigating the effects of exercise training and rehabilitation programmes in CF showed increased peak $\dot{V}O_2$ and peak minute ventilation (peak $\dot{V}_E$) values, and reduced heart rates (HR) at submaximal workloads, indicating improved CPF [11, 16, 19, 25, 37]. Interestingly, the observed training effects are independent of patients' disease severity. Thus, even patients with severe CF lung disease are able to improve their CPF. Furthermore, it has been established that children with CF had higher activity levels, greater aerobic fitness, enhanced nutritional status, and significantly lower progression of disease [34].

Gulmans et al. investigated the effects and acceptability of a 6-month home-based cycling programme in 14 children (age 14.1 years) with mild-to-moderate CF lung disease [38]. The programme consisted of 5 ergometer cycling sessions per week for 20 min each with the training intensity progressively increasing over time. In the first week the training intensity started at 50% of maximal workload, increasing up to 60% in the following weeks until the next measurement was up to 70% of maximal workload. Once a week, the programme was supervised by a physiotherapist. HR was measured every three minutes, and the workload was adjusted to reach target training intensities between 140–160 beats per minute (70%–80% of predicted maximal). After the training period, peak $\dot{V}O_2$ per kg body mass as well as per kg FFM increased significantly. Moreover, leg muscle strength for knee extensors and ankle dorsiflexors significantly increased during the training period. Unfortunately, the acceptability of the programme was low, probably due to the somewhat "monotonous" cycling programme. In general, adherence to treatments is challenging in CF, especially adherence to regular exercise and physical activity. However, the participation in the prescribed exercise training programme has been shown to increase perceived competence and self-esteem in the children as important mediators to adherence behaviour. This seems of particular relevance for patients in terms of maintaining an active lifestyle and adherence to training into the long term. We suggest a training programme that should focus on the individual interests of the children including preferences for sport activities. The study may have benefited by including different activities to maintain motivation and adherence to training [38].

Furthermore, in a 12-week randomised and controlled study following a standardised anaerobic training programme in eleven children with CF, a significant increase in peak $\dot{V}O_2$ ($mL\cdot min^{-1}$) in the training group was observed. The supervised training consisted of two 30–45 min exercise sessions per week of special anaerobic exercises, for example, sprints, chest passes, exchange runs, and so forth. all performed at near maximum intensities. The detailed training programme can be found elsewhere: (http://www.chestjournal.org/content/full/125/4/1299/DC1). In contrast, peak $\dot{V}O_2$ was significantly decreased in the control group ($N = 9$). After a 12-week follow up all parameters concerning aerobic fitness decreased to pretraining levels [16].

Schneiderman-Walker et al. investigated the long-term effects of regular exercise training in a 3-year study. Children and adolescents with mild to moderate CF lung disease aged 7–19 years were randomly assigned to either an exercise intervention or control group. The exercise group was instructed to perform a minimum of 20 minutes in their favourite endurance-related activities three times per week. In addition, the patients were advised to monitor their HR while exercising at a training intensity of 70%–80% of maximum HR. Evaluation of training and monitoring was done during telephone and clinical conversations. Exercise capacity was measured during cycle ergometry. At the end of the intervention, no significant differences in the annual rate of decline in peak $\dot{V}O_2$, peak heart rate (peak HR), and peak $\dot{V}_E$ between either group were found. However, the intervention group demonstrated a significantly lower annual decline in FEV_1 and vital capacity (VC). Patients in the exercise group remained compliant during the study period and reported better well-being [18].

2.1.2. Anaerobic Responses to Exercise. Anaerobic activities are characterised by high intensities of short durations (lasting typically up to 30 s), being predominantly fuelled by nonoxidative sources of ATP resynthesis. Previous studies investigating anaerobic performance of children and adults with CF showed lower values compared to healthy subjects [39–41]. Furthermore, children with CF with higher levels of habitual activity have been found to possess increased anaerobic power during the Wingate Anaerobic Test (WAnT). These higher levels of activity are likely influenced by several factors such as the extent of malnutrition, muscle mass, mitochondrial abnormalities, and CF genotype [29, 30, 34, 40, 42, 43].

Boas et al. found lower power outputs in the WAnT in 41 male adolescents with CF compared to healthy controls [42]. Subgroup analysis of subjects with CF revealed that nutritional status and sexual maturation rather than pulmonary function may affect anaerobic exercise performance. In their observation, subjects with higher salivary testosterone ($>4.0\,ng\cdot dL^{-1}$) had higher power outputs in both absolute terms and relative to lean body mass compared to subjects and lower salivary testosterone values ($<4.0\,ng\cdot dL^{-1}$). Furthermore, body mass index (BMI) was associated with higher anaerobic performance, indicating higher power output values. Categorising the patients regarding their pulmonary function showed no differences, however, this population had almost normal lung function values (FEV_1, $90.2 \pm 24.2\%$ predicted).

Another study showed significant improvements in anaerobic parameters in the WAnT following a 12-week individualised anaerobic training programme. Eleven children with CF lung disease trained 30–45 minutes two times per week. Peak power and mean power per kilogram FFM significantly increased in the training group, as anaerobic parameters did not change in the control group. After a 12-week followup period, anaerobic performance and quality of life remained improved whereas most outcome parameters decreased to pretraining levels [16].

In another related study, Selvadurai et al. investigated the relationship between fitness and CF genotype in 79 children with a wide range of disease severity. The class of CF transmembrane conductance regulator (CFTR) mutation was significantly correlated with anaerobic and aerobic performance, BMI, and pulmonary function. Patients with class I and II CFTR mutation had the lowest peak anaerobic power in the WAnT compared to those with classes III, IV, and V CFTR mutations, respectively [43].

Unfortunately, most training studies in CF are of short duration, and longitudinal data are lacking, especially in the paediatric population. Longitudinal and controlled studies are required to verify training effects in association with disease progression in CF and decline in pulmonary function and peak $\dot{V}O_2$. Studies, documenting less or no effects after exercise training on CPF, are most likely due to a low number of study subjects, lack of a control group or lack of training supervision, and poor compliance [25, 44]. Further research is warranted to assess the effects of different training methods longitudinally (aerobic versus anaerobic training versus a combination of both training regimes). More detailed information regarding training protocols (intensity, duration, and rest periods) would be advantageous to therapists and health care providers working with children with CF. Furthermore, when working with children the fun component needs to be emphasised, while group activities may be the preferred choice rather than isolated training (i.e., cycling or stepping), infection control permitting. Trampolining, for example, as a popular although controversial activity, has been discussed in the paediatric population and CF lung disease, especially due to the increased risk potential for injuries [45–47]. However, providing there is particular focus on safety issues and supervision, trampolining can be an effective adjunct to regular airway clearance techniques or even as part of physiotherapy in CF [48]. In habitual daily life patients with CF are faced with certain barriers and challenges according to their participation in regular exercise and habitual physical activity [14]. Parents should be encouraged to exercise with their children and serve as role models (i.e., aiming to increase habitual physical activity levels). Based on the training studies available in children and adolescents with CF, there is no definitive evidence regarding the sustainability of training effects in the long term (i.e., months to years).

Table 1: General exercise and training recommendations.

	Patients with mild to moderate CF lung disease	Patients with severe CF lung disease
Recommended activities	Cycling, walking, hiking, aerobics, running, rowing, tennis, swimming, strength training, climbing, roller-skating, (trampolining)	Ergometric cycling, walking, strengthening exercises, gymnastics, and day-to-day activities
Method	Intermittent and steady-state	Intermittent
Frequency	3–5 times per week	5 times per week
Duration	30–45 minutes	20–30 minutes
Intensity	70%–85% HRmax; 60%–80% peak $\dot{V}O_2$; LT; GET	60%–80% HRmax; 50%–70% peak $\dot{V}O_2$; LT; GET
Oxygen supplementation	Indicated, if SaO_2 drops below 90% during exercise	Indicated, if SaO_2 drops below 90% during exercise (cave: resting hypoxia)
Activities to avoid	Bungee-jumping, high diving, and scuba diving	Bungee-jumping, high diving, scuba diving, and hiking in high altitude
Potential risks associated with exercise, and training	Dehydration Hypoxemia Bronchoconstriction Pneumothorax Hypoglycaemia* Hemoptysis Oesophageal bleedings Cardiac arrhythmias Rupture of liver and spleen Spontaneous fractures**	

HRmax: maximum heart rate; peak $\dot{V}O_2$: peak oxygen consumption; LT: lactate threshold; GET: gas exchange threshold; SaO_2: oxygen saturation.
*Depending on the existence of an impaired glucose tolerance.
**Depending on the existence of untreated CF-related bone disease.

2.2. Possible Risks Associated with Exercise Training in CF. Specific risks of exercise training in CF are presented in the table. During prolonged exercise, as a consequence of excessive sweat and sodium losses, children with CF are advised to drink repeatedly (i.e., every 15–20 min), and ideally including approximately 50 mmol$\cdot$L^{-1} sodium chloride in their drink [49]. Especially, in hot conditions, children may underestimate their fluid needs with the risk to undergo excessive dehydration [50].

Certain sports in this population should also be viewed with caution. For example, CF patients with portal hypertension with significant enlargement of spleen and liver should, as a precaution, be advised against participation in contact sports. Patients participating in physical activities which take place at high altitudes (e.g., skiing) should be monitored, especially if the patient is already hypoxic. Furthermore, episodes of acute right heart failure induced by a combination of altitude and high intensity exercise have been documented [51]. During diving activities air trapping could occur in patients with lung disease, on ascent the air expands, with risk of development of pneumothorax [52]. Exercise-induced hypoxemia is a potential hazard for patients with CF, thus participation in high-intensity exercise needs consideration. However, soon after the termination of high intensity efforts, SaO_2 returns to pre-exercise levels, while there is no evidence that brief exercise-induced hypoxemia causes damage to the child with CF [53]. Cough with sputum may be observed during exercise in patients; however, this is indicative of airway clearance.

General guidelines for clinical exercise testing [54, 55] and training in patients with chronic disease are beyond the scope of this paper and can be found elsewhere [49]. The table summarises a selection of recommended exercises, including training intensities for patients with CF. The optimal training mode for CF patients has yet to be defined. Our recommendations (see Table 1) are based on training studies available, as well as, our own clinical and practical experience in the work with children and adolescents with CF. We support the approach of combining endurance and strengthening activities as well as exercises to improve flexibility, balance, and motor skills [7]. In addition to exercise training, an active lifestyle is generally recommended to improve exercise capacity, for example, using stairs instead of an elevator. We therefore recommend including a detailed description of training methods and parameters (duration, intensity, frequency, and rest periods) in future studies. In particular, this may help comparing results of different training studies. Despite the beneficial effects of regular (structured) exercise, habitual physical activity levels (activities that can easily incorporated in daily life) have been shown to contribute to the overall health in children with CF.

3. Conclusion

Physical activity is well recognized as part of health care and rehabilitation programmes in CF; however the relationships between activity, fitness, and health are still poorly understood. Higher levels of habitual activity have been associated with higher aerobic and anaerobic capacity, a better quality of life, and improved survival. However, longitudinal studies are needed to support and justify programmes of regular exercise on the overall health status of children and adolescents with CF. To date, there is no evidence that children and adolescents with CF should not be physically active in daily life. Moreover, as part of their CF management, it would be desirable to inform patients, and their parents about the beneficial effects of exercise, but also its potential risks, and additionally provide patients with training recommendations. Ideally, these would be based on previously performed standard clinical exercise testing. It is necessary to instruct clinicians, health care support staff, patients and parents regarding adequate exercises and sports activities during rehabilitation programmes that can be implemented in normal daily life.

Abbreviations

CF:	Cystic fibrosis
CPF:	Cardiopulmonary fitness
Peak $\dot{V}O_2$:	Peak oxygen consumption
FEV_1:	Forced expiratory volume in 1 s
FFM:	Fat free mass
ATP:	Adenosine Triphosphate
$\dot{V}O_2$:	Oxygen consumption
peak $\dot{V}_E$:	Peak ventilation
HR:	Heart rate
peak HR:	Peak heart rate
VC:	Vital capacity
WAnT:	Wingate Anaerobic Test
BMI:	Body mass index
CFTR:	Cystic fibrosis transmembrane conductance regulator
SaO_2:	Oxygen saturation
$\dot{V}_E$:	Expired ventilation
$\dot{V}CO_2$:	Volume of carbon dioxide
ECG:	Electrocardiogram
CO_2:	Carbon dioxide
FVC:	Forced vital capacity
GET:	Gas exchange threshold
MVV:	Maximum voluntary ventilation
f_R:	Respiratory rate
$P_{ET}CO_2$:	End-tidal pressure of carbon dioxide.

Competing Interests

The authors do not have any competing interests to declare.

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Research Article

Developmental Changes in Hemodynamic Responses and Cardiovagal Modulation during Isometric Handgrip Exercise

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The purpose of this study was to examine differences in pressor response and cardiovagal modulation during isometric handgrip exercise (IHG) between children and adults. Beat-to-beat heart rate (HR) and blood pressure were measured in 23 prepubertal children and 23 adults at baseline and during IHG. Cardiovagal modulation was quantified by analysis of HR variability. Mean arterial pressure responses to IHG were greater in adults compared to children ($P < .05$) whereas there were no group differences in HR responses ($P > .05$). Children had a greater reduction in cardiovagal modulation in response to IHG compared to adults ($P < .05$). Changes in mean arterial pressure during IHG were correlated with baseline cardiovagal modulation and force produced during isometric contraction ($P < .05$). In conclusion, differences in pressor reflex response between children and adults cannot be solely explained by differences in autonomic modulation and appear to be associated with factors contributing to the force produced during isometric contraction.

1. Introduction

Heart rate (HR) variability is a reflection of the interaction between the parasympathetic and sympathetic nervous system influences on the cardiac sinus node [1]. Cross-sectional studies in infants, children, and young adults showed that total HR variability increases up to 6 years of age and declines thereafter, suggesting that autonomic modulation of the sinus node changes with growth and maturation [2–4]. Previous studies have also shown that children have lower resting cardiovagal baroreflex sensitivity (BRS) compared to adolescents and young adults, suggesting that cardiovascular reflex autonomic regulation evolves from childhood to adulthood [3].

The majority of studies investigating the effects of growth on autonomic regulatory mechanisms have focused on measurements obtained during resting conditions [2–4]. The autonomic nervous system, however, plays a paramount role in cardiovascular adaptations to short-term stressors [5]. Therefore, examining the autonomic adjustments to physical stressors may have a greater physiological relevance and provide more useful information than assessing baseline autonomic function. Accordingly, we have previously shown that children 12 years of age had faster HR recovery from exercise associated with greater postexercise HR variability when compared to adolescents aged 15 years [6], suggesting that children had greater parasympathetic reactivation during recovery from exercise compared to adolescents. Others have shown that during standing the percent increase in the low frequency power of HR and systolic blood pressure (BP) variability (i.e., indicators of sympathetic modulation) was higher in adolescents compared to preadolescents [7]. Collectively, these findings suggest that the effects of maturation on autonomic modulation extend to conditions that are characterized by physical stress, such as exercise and orthostatic stimuli.

Isometric exercise provides a convenient and easy way to activate the cardiovascular system and define the role of the autonomic nervous system in the exercise response [8]. Isometric muscle contraction evokes large increases in mean arterial pressure (MAP) and HR with a minor rise in central hemodynamics [9]. These cardiorespiratory responses are mediated by autonomic neural adjustments [10]. Previous studies showed differences in pressor response to isometric handgrip exercise (IHG) between children and adults, with children exhibiting a lower pressor response (smaller BP changes from baseline) compared to adults [11]. To what extent these findings reflect age-associated differences in autonomic regulatory mechanisms in response to isometric contraction is unknown.

Thus, the main purposes of this study were to (1) examine age-associated differences in cardiovascular responses to IHG, and (2) examine differences between children and adults in cardiovagal autonomic modulation and baroreflex sensitivity during isometric contraction. It was hypothesized that children would have a smaller pressor response compared to adults and a greater reduction in cardiovagal modulation during isometric exercise. In the present study, cardiovagal modulation was quantified by analysis of HR variability in the frequency (high frequency power, HF) and time domain (square root of the mean of the sum of the squares of differences between adjacent RR-intervals, RMSSD, and coefficient of variation (CVS)).

2. Methods

2.1. Subjects. Twenty three healthy children (7–9 years) and 23 healthy young adults (20–25 years) participated in this study. All participants were physically active but did not participate in any organized endurance exercise training program. Exclusion criteria included any medication that alters BP, HR, and autonomic regulation, any known metabolic and cardiovascular diseases, smoking, and hormonal contraceptives. Maturity status was assessed using evaluation of secondary sexual characteristics (Tanner stages for breast and pubic hair) to ensure there were no signs of pubertal development in any of the children. According to this evaluation, all children were prepubertal. All adult females were tested within the first 10 days of their menstrual cycle. The study was approved by the Institutional Review Boards of Syracuse University and SUNY Upstate Medical University and all adult participants, and the parents of the children provided written informed consent and all children provided written assent before testing.

2.2. Experimental Design. Two visits were required for the completion of the study. On the first visit, all participants completed a medical history and a physical activity questionnaire and were familiarized with the testing procedures. In addition, measurements of height and weight, and maturity assessment were obtained. On the second visit, the participants completed a questionnaire to verify that they had followed the pretesting instructions. Participants were instructed to refrain from food and caffeinated products for 4 hours and from vigorous exercise and alcohol for 24 hours before the tests. Following a 10 minutes quiet rest, beat-to-beat arterial pressure and continuous electrocardiogram (ECG) were recorded before and during a 3-min IHG task.

2.3. Isometric Handgrip Exercise. All participants were tested in the seated position with their elbow flexed at 90°. Maximal isometric force of the dominant hand was measured three times 1-2 minutes apart using a calibrated handgrip dynamometer (Biopac Systems Inc., Santa Barbara, CA). If the trials were not within 10% of each other, additional trials were performed until a plateau was reached. The highest of the 3 values (kg) was defined as the subject's maximal voluntary contraction (MVC). Isometric force was recorded at a frequency of 1000 Hz using a 16-bit data acquisition card (MP100, Biopac Systems, Inc., Santa Barbara, CA). After determination of MVC, all subjects performed a sustained isometric contraction at 30% MVC for 3 minutes. Visual feedback via a computer monitor located 1 m directly in front of the subject and verbal encouragement to maintain the desired force were provided throughout the test. Subjects were instructed to avoid Valsalva maneuver and relax the muscles that did not participate in the isometric contraction.

2.4. Beat-to-Beat Hemodynamics. Following 10 minutes of quiet rest (after determination of MVC), continous ECG, and beat-to-beat arterial pressure were recorded for 2 minutes at rest (baseline) and during 3 minutes of IHG. The subjects were tested in the seated position. Heart rate was recorded using a modified CM5 ECG lead, interfaced with data collection and interpretation software (Biopac Systems Inc., CA) at a sampling rate of 1000 Hz. Arterial pressure was measured continuously using a BP finger cuff placed in the middle-finger of the nonexercising hand (Finometer, FMS, the Netherlands). The arterial pressure recordings were performed at a sampling rate of 200 Hz. The Finometer continuously monitors finger arterial pressure using the volume-clamp method of Penaz and performs reconstruction of brachial artery pressure waveform and level from the finger pressure using generalized waveform inverse modeling. This method has been shown to accurately track hemodynamic changes from baseline [12]. Previous studies in both adult and pediatric subjects found that continuous arterial pressure measurements via finger plethysmography slightly underestimated systolic BP (SBP) by 1.9 mmHg and diastolic BP (DBP) by 5.1 mmHg when compared with standard auscultatory techniques [13]. Small within-subject variability (3.8 mmHg for SBP and 4.1 mmHg for DBP) and similar accuracy between children and adults have been also reported, regarding the finger plethysmographic techniques [13]. It was suggested that finger plethysmography is useful for noninvasive assessment of autonomic control and cardiovascular reflexes involving short-term and rapid BP changes in both children and adults [13].

2.5. Data Analyses

2.5.1. Hemodynamic Variables. Systolic BP, DBP, and MAP were derived from the arterial pressure waveform obtained by the finger plethysmography. Heart rate was calculated from the ECG tracings and stroke volume was calculated from the arterial pressure signal using the arterial pulse wave contour method [14]. Cardiac output was calculated as the product of HR and stroke volume. To account for differences in body size between children and adults, stroke volume and cardiac output are expressed relatively to subjects' body surface area (BSA) and are presented as stroke index and cardiac index, respectively. Total peripheral resistance (TPR) was calculated using the equation: TPR = (MAP/cardiac index) ∗ 80. Baseline values were derived from the average of 3 minutes of data for each hemodynamic variable and IHG values represent the average of the last minute of exercise, during which the maximum values for all subjects were observed.

2.5.2. Heart Rate Variability and Baroreflex Sensitivity Analyses

Frequency Domain Analysis. R-R interval time event series were generated from successive HR peaks (WinCPRS, Absolute Aliens Oy, Turku, Finland). Epochs of 120 seconds were analyzed for each condition (i.e., 120 seconds of baseline and the last 120 seconds of IHG measurements) and for each subject. The nonequidistant waveforms were resampled at 5 Hz and passed through a low-pass filter with a cutoff frequency of 0.5 Hz. The spectrum of each signal was calculated using a maximum entropy method (autoregressive modeling). The model order was chosen as the one that minimized Akaike's final prediction error figure of merit. Autoregressive modeling requires a small sample space and therefore, it can be used for analysis of very short-time series [15]. However, this method is vulnerable to nonstationarity (i.e., the degree of signal deviation from baseline) [15]. In this study, stationarity was determined to justify the use of autoregressive modeling (WinCPRS, Absolute Aliens Oy, Turku, Finland). A stationarity value close to zero reflects a stationary signal, while an increase in this value represents an increase in nonstationarity [16]. In this study, mean stationarity of the collected signal at baseline was 0.50 ± 0.02, while mean stationarity for IHG was 0.63 ± 0.03.

Spectral power was expressed as the integrated areas in low (LF: 0.05–0.15 Hz), high (HF: 0.15–0.4 Hz), and total (TP: 0.05–0.4 Hz) frequency ranges. The HF power was used as an index of cardiovagal modulation and was expressed in msec^2 [17]. In addition, considering the variation in R-R intervals attributable to HF power and the changes in this variation from baseline to IHG, we calculated the coefficient of component variance using the formula: $CCV_{HF} = \sqrt{HF\ power}/(\text{mean R-R interval}) * 100$ (%) [18].

The reproducibility of HR variability measurements has been previously evaluated in our lab in adolescents and young adults and intraclass correlation coefficients were 0.964 and 0.933 ($P < .05$) for LF (msec^2) and HF (msec^2), respectively [6].

Time Domain Analysis. Heart rate variability was also evaluated in the time domain calculating the mean normal-to-normal R-R intervals and the normal-to-normal R-R intervals differences [15]. These variables were then assessed by statistical analyses providing the following statistics: the standard deviation of the normal-to-normal R-R intervals (SDNN) and the square root of the mean of the sum of the squares of differences between adjacent R-R intervals (RMSSD). In order to control for differences in HR periods from baseline to IHG and between groups, the coefficient of variation (CVS = SDNN/R-R interval) was calculated. All of these measures recognize short-term variations in HR and therefore, estimate HF cyclic components, which are associated with cardiovagal modulation [15].

Cardiovagal Baroreflex Sensitivity Analysis. Cardiovagal baroreflex sensitivity (BRS) was determined from the coupling between interbeat intervals and SBP, which were collected via finger plethysmography [19]. This technique has been previously described in [6]. Briefly, beat-to-beat time series of arterial pressure and pulse intervals were searched for sequences of three or more consecutive heart beats in which the pulse intervals and the corresponding SBP increased (WinCPRS, Absolute Aliens Oy, Turku, Finland). These sequences were defined as "baroreflex sequences" and a linear regression line was applied to each of them. The mean slope of all regression lines determined for each subject and for each condition (baseline, IHG) was calculated and taken as a measure of integrated spontaneous BRS. Only sequences with correlations equal or greater than 0.85 were accepted. This measure was used to evaluate the arterial baroreflex modulation of sinus node and its changes from baseline to IHG.

2.6. Statistical Analysis. Independent *t*-test was used to examine group differences in subject characteristics (age, height, weight, BMI, BSA, MVC). The HR variability frequency domain and BRS measures were not normally distributed and therefore, they were transformed to natural logarithms (ln) before statistical analysis. A repeated-measures analysis of covariance (ANCOVA), with one between (group: children versus young adults) and one within (task: baseline versus IHG) factor was carried out to examine differences between children and adults in hemodynamic responses to IHG. Baseline values and BMI were used as covariates to control for the influence of these factors on group responses. In addition, a 2×2 ANCOVA with repeated measures was used to determine differences between children and adults in HR variability and BRS responses to IHG. Body surface area and baseline values of HRV were used as covariates to control for their influences on the subjects' responses.

The main assumptions of the analysis of covariance were tested and were met. Specifically, BMI was significantly correlated with all hemodynamic variables, BSA was significantly correlated with all HR variability parameters, and these correlations were the same within each of the populations involved in the study (equal regression slopes).

TABLE 1: Subject characteristics.

Variables	Young adults	Children
No (males/females)	23 (13/10)	21 (12/9)
Age (yr)	22.0 ± 0.3	8.3 ± 0.2*
Height (cm)	171.4 ± 1.7	132.6 ± 1.8*
Weight (kg)	76.9 ± 3.7	34.3 ± 2.7*
BMI (kg/m^2)	26 ± 1	19 ± 1*
BSA (m^2)	1.85 ± 0.04	1.05 ± 0.04*
MVC (kg)	56.2 ± 4.1	19.8 ± 1.3*

Values are means ± SE.
BMI: body mass index; BSA: body surface area; MVC: maximal voluntary contraction.
*$P < .05$, group differences.

Pearson-moment correlations were used to assess the relationship between pressor reflex response to IHG (ΔMAP = $MAP_{IHG} - MAP_{baseline}$) and age, BMI, BSA, 30% MVC (absolute intensity in kg), CCV_{HF}, and CVS. A stepwise linear regression model of ΔMAP on the above independent variables was performed. Gender was added as a predictor in this model. The significance level of all statistical analyses was set at alpha = 0.05. Data are presented as means ± standard error (SE). Unadjusted and adjusted means as well as unadjusted and adjusted SE are reported for the ANCOVA results.

3. Results

3.1. Subject Characteristics. Table 1 illustrates the subject characteristics for both groups. As expected, children were younger, shorter, and lighter compared to adults and had lower BMI, BSA, and MVC ($P < .05$). In addition, baseline hemodynamic measures were different between groups. Specifically, children had lower BP (SBP, DBP, MAP), stroke index and cardiac index, and greater HR and TPR at baseline ($P < .05$, Table 2).

3.2. Hemodynamic Responses to Handgrip Exercise. Analysis of covariance was used to determine whether children's hemodynamic responses to IHG differ from those of the adult group, adjusting for baseline measures and BMI. Table 2 displays unadjusted means and SE for all the hemodynamic measurements obtained in the present study. The adjusted means (adjusted to the covariate influence) and SE are presented in Figures 1(a)–1(c) and Figures 2(a)–2(d).

After adjustment for variation in baseline values and BMI, significant group by task interactions were found on SBP, DBP, and MAP, showing that BP significantly increased in response to IHG in both groups but this increase was greater in adults compared to children ($P < .05$, Figures 1(a)–1(c)). Heart rate also increased in response to IHG ($P < .05$) but there were no differences between groups in the magnitude of the response ($P > .05$, Figure 2(a)).

After controlling for baseline values, significant task by group interactions on stroke index, cardiac index, and TPR were also found ($P < .05$, Figures 2(b)–2(d)). Specifically, young adults exhibited an increase in stroke index and cardiac index during IHG ($P < .05$) and no change in TPR ($P > .05$) whereas children showed no change in stroke index ($P > .05$) and an increase in cardiac index and TPR in response to IHG ($P < .05$). Of note, we did not covary for BMI in this analysis because variations in body size were accounted for by expressing cardiac output, stroke volume, and TPR relatively to BSA.

3.3. Heart Rate Variability and Baroreflex Sensitivity in Response to Handgrip Exercise

3.3.1. Time Domain Parameters. Children had greater baseline RMSSD and CVS ($P < .05$). An analysis of variance with repeated measures was initially employed to examine differences in HR variability responses to IHG between groups. The results of this analysis showed that R-R intervals decreased in response to IHG in both groups (main effect, $P < .05$), and this decrease was greater in adults compared to children (group by task interaction, $P < .05$). The time domain parameter CVS was reduced in response to IHG only in children (group by task interaction, $P < .05$) whereas RMSSD decreased in both group (main effect, $P < .05$). When we controlled for BSA and baseline values, the task by group interactions presented above were no longer significant ($P > .05$). Table 3 displays unadjusted means and SE, and adjusted means and SE for R-R intervals, RMSSD, and CVS measures at baseline and in response to IHG.

3.3.2. Frequency Domain Analysis. Children had greater baseline ln HF and CCV_{HF} compared to adults ($P < .05$), but there were no group differences in baseline ln TP ($P > .05$). Analysis of variance with repeated measures revealed task by group interactions on ln HF and CCV_{HF}. Specifically, children had a significant reduction in ln HF and CVV_{HF} in response to IHG ($P < .05$), while adults had no change in these variables ($P > .05$). When controlling for BSA and baseline values the task by group interactions presented above were no longer significant ($P > .05$). Table 3 displays unadjusted means and SE, and adjusted means and SE for all frequency domain parameters at baseline and in response to IHG.

3.3.3. Cardiovagal Baroreflex Sensitivity. There were no differences in baseline cardiovagal baroreflex sensitivity between groups (ln BRS, young adults: 2.6 ± 0.09 msec/mmHg versus children: 2.85 ± 0.10 msec/mmHg, $P > .05$, Table 3). Baroreflex sensitivity was reduced in both groups in response to IHG but the extent of this change was similar between groups (main effect, baseline: 2.74 ± 0.07 msec/mmHg versus IHG: 2.39 ± 0.08 msec/mmHg, $P < .05$).

3.3.4. Correlations. Changes in MAP (ΔMAP) were inversely correlated with baseline CCV_{HF} ($r = -0.360$, $P < .05$) and CVS ($r = -0.352$, $P < .05$) and were positively correlated with BSA ($r = 0.469$, $P < .01$), BMI ($r = 0.339$, $P < .05$), age ($r = 0.470$, $P < .01$), and the force produced at 30% MVC ($r = 0.526$, $P < .01$). After controlling for

Table 2: Hemodynamic variables (unadjusted means) at baseline and in response to handgrip exercise.

Variables	Young adults Baseline	Young adults IHG	Children Baseline	Children IHG
SBP (mmHg)	117.5 ± 2.2	148.6 ± 3.7	107.9 ± 2.0‡	122.1 ± 2.7*†
DBP (mmHg)	71.3 ± 1.2	91.9 ± 2.1	64.6 ± 2.0‡	78.1 ± 2.5*†
MAP (mmHg)	88.5 ± 1.5	114.9 ± 2.7	82.8 ± 2.4‡	96.4 ± 2.4*†
HR (bpm)	68.8 ± 2.0	82.6 ± 2.1	84.0 ± 2.0‡	93.5 ± 2.2*
Cardiac index (L/min/m^2)	3.1 ± 0.1	3.9 ± 0.2	1.5 ± 0.06‡	1.7 ± 0.07*†
Stroke index (mL/beat/m^2)	45.5 ± 1.5	49.0 ± 1.4	17.6 ± 0.6‡	17.9 ± 0.7*†
TPR (dyn/sec·cm^{-5}·m^2)	2344 ± 90	2358 ± 85	4631 ± 224‡	4802 ± 223

Means ± SE, values are not adjusted for the influence of the covariates.
*$P < .05$, measures during IHG are different from baseline (main effect); †$P < .05$, task by group interaction; ‡$P < .05$, group differences in baseline hemodynamic variables.
SBP: systolic blood pressure; DBP: diastolic blood pressure; MAP: mean arterial pressure; HR: heart rate; TPR: total peripheral resistance.

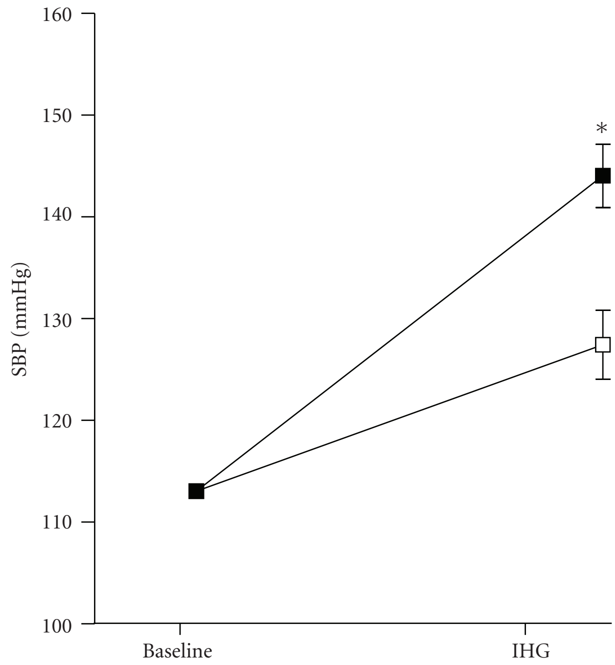
BSA (partial correlations), the correlations between ΔMAP and cardiovagal indices CCV_{HF} and CVS were no longer significant ($P > .05$) whereas the correlation between ΔMAP and force produced at 30% MVC remained significant ($P < .05$). The prediction model of the stepwise regression equation indicated that the only significant contributor to variations in ΔMAP was the force produced (30% MVC) during IHG ($R^2 = 0.526$, $P < .001$).

4. Discussion

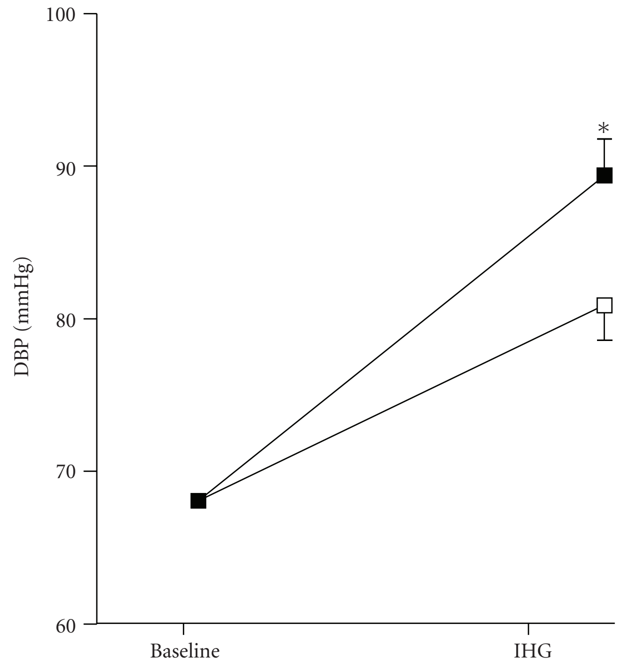
The main findings of this study were as follows: (1) children exhibited a lower exercise pressor response compared to young adults, (2) children had a greater reduction in cardiovagal modulation compared to adults during isometric exercise, (3) the differing patterns of autonomic modulation during IHG between children and adults were determined by the greater baseline cardiovagal modulation found in children and their smaller body size, and (4) the magnitude of the pressor response to isometric muscle contraction was directly associated with the force produced at 30% MVC and inversely correlated with baseline cardiovagal modulation.

During isometric exercise, HR, and cardiac output increase, and TPR remains the same or slightly increases, resulting in an increase in SBP, DBP, and MAP [20]. These hemodynamic responses have been well established in adults whereas there is limited data on prepubertal children's responses to isometric contraction. The findings of the present study are in agreement with previous investigations showing differences in pressor response to IHG between children and adults, with children having a lower BP response to isometric exercise [11]. In addition, children showed smaller increases in cardiac index (adults: +26% versus children: +13%) during IHG compared to adults. This lower cardiac index response can be attributed to lower stroke index during exercise, which was only partially compensated for by an elevation in HR levels. In addition, children exhibited greater resting and exercise TPR. In a previous study, Laird and colleagues [21] showed that adolescents increased SBP, DBP, MAP, and cardiac index but had no change in stroke volume and TPR in response to IHG at 25% MVC. These investigators, however, did not collect data on adults and the children participated in their study were older than our prepubertal subjects. Our data are in agreement with previous studies reporting differences in cardiovascular responses to submaximal aerobic exercise between prepubertal children and young adults [22]. In those studies, the differing hemodynamic responses to exercise between children and adults were related to children's smaller hearts and smaller amount of muscle mass being recruited at a given rate of work [22]. The smaller TPR response to exercise found in adults has been previously attributed to greater accumulation of metabolites in adult subjects [23, 24], which contributes to greater vasodilatation [25].

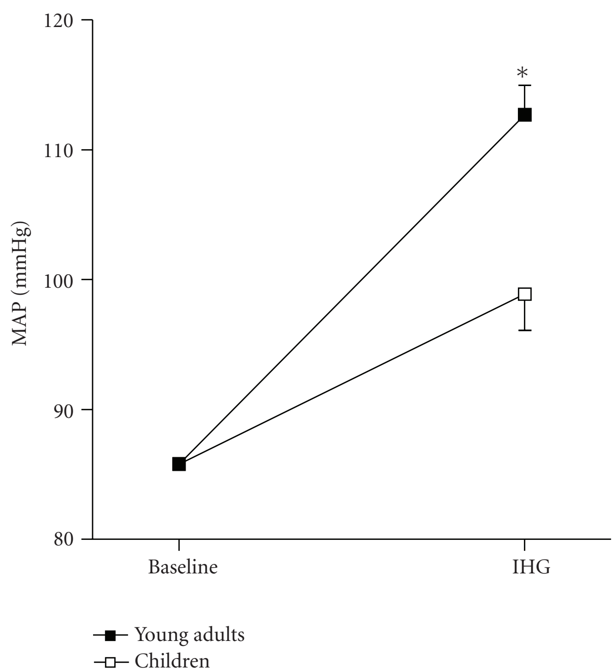
Currently, the mechanisms responsible for the different hemodynamic responses to isometric exercise in prepubertal children are unknown. The cardiovascular responses to isometric contraction are mainly mediated by autonomic adjustments involving sympathetic nervous system activation and vagal withdrawal [10]. Specifically, the early rise in BP is due to tachycardia mediated primarily by a decrease in efferent cardiac vagal activity [9, 26] whereas the rise in BP during sustained contraction is due to an increase in efferent sympathetic activity [9]. Consequently, differing patterns in the pressor reflex during an isometric stimulus may reflect differences in autonomic modulation between children and adults. To the best of our knowledge, this is the first study to examine the role of autonomic modulation in exercise pressor reflex response of pediatric subjects. Although children and adults had similar HR responses to IHG, the reduction in HF power and the time domain parameters of HR variability was greater in children. Pharmacological studies have previously reported that alterations in HR variability reflect changes in parasympathetic modulation of the sinus node [27], which led us to conclude that children had a greater reduction in cardiovagal modulation during isometric contraction compared to adults. Changes in cardiovagal activity (i.e., vagal withdrawal) are critical during isometric contraction because they result in a BP increase (secondary to a tachycardic response) at the onset of the exercise task to match the intensity of the exercise stimulus [9].



(a)



(b)



(c)

Figure 1: Systolic blood pressure (a), diastolic blood pressure (b) and mean arterial pressure (c) responses to isometric handgrip exercise in children and young adults. SBP: systolic blood pressure; DBP: diastolic blood pressure; MAP: mean arterial pressure; IHG: isometric handgrip exercise. The adjusted means (adjusted to the influence of the covariates) are presented as means ± SE. $^{*}P < .05$, task by group interaction.

After controlling for baseline values, there were no group differences in cardiovagal modulation responses to IHG. This suggests that the greater reduction in cardiovagal activity during exercise in children compared to adults was mainly due to children's elevated cardiovagal activity at baseline, which modulates the extent to which efferent vagal withdrawal will take place under the influence of a physical stress. This finding is in agreement with the law of initial value that states that the outcome of an autonomic response depends on the already existing state of

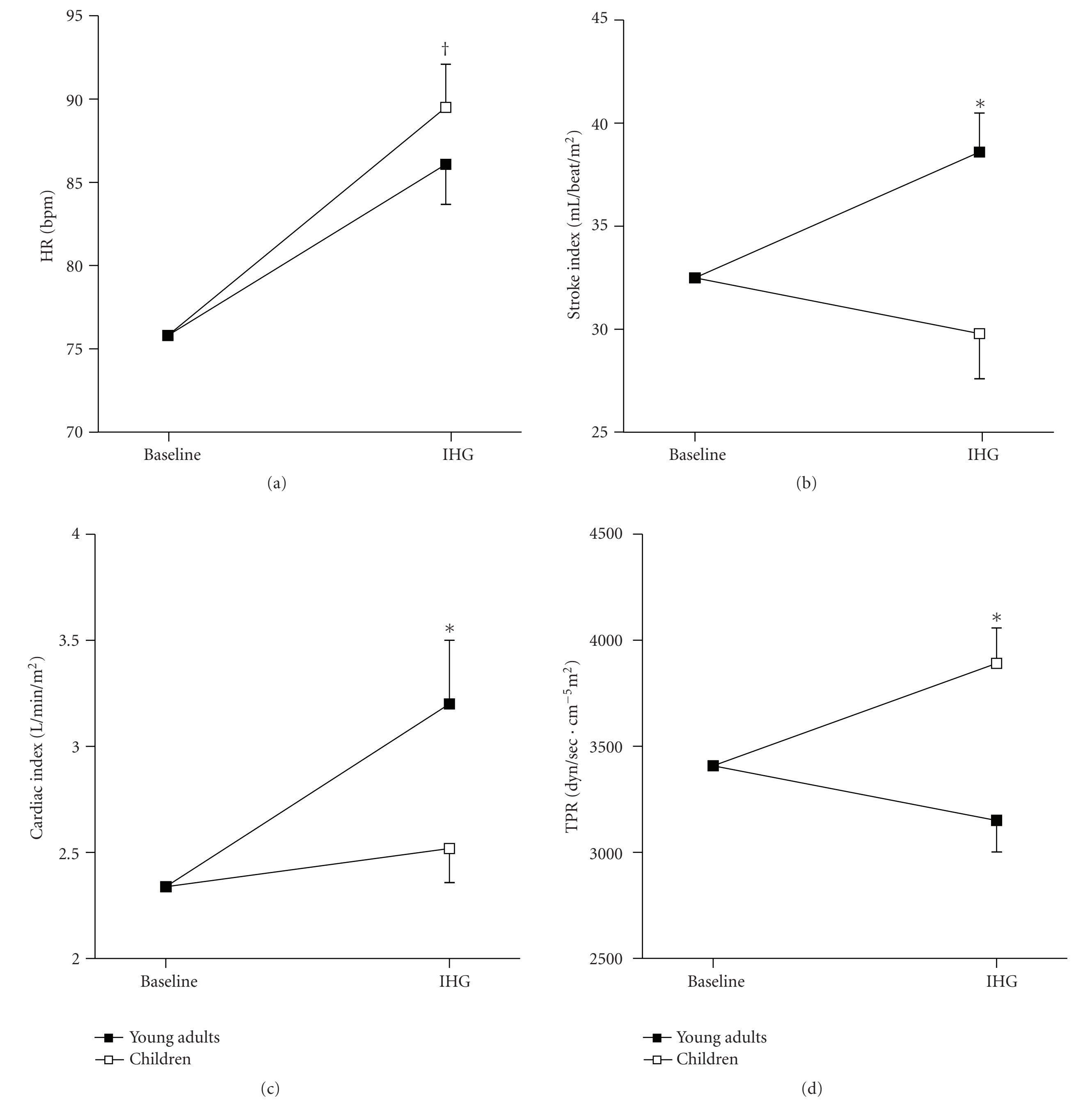


Figure 2: Heart rate (a), stroke index (b), cardiac index (c), and total peripheral resistance (2D) responses to isometric handgrip exercise in children and young adults. HR: heart rate; TPR: total peripheral resistance; IHG: isometric handgrip exercise. The adjusted means (adjusted to the influence of the covariates) are presented as means ± SE. $^*P < .05$, task by group interaction; $^\dagger P < .05$, task effect.

excitation of the autonomic nerves [28]. The present study also found that baseline cardiovagal modulation (CVV_{HF} and CVS) was inversely correlated with changes in MAP from baseline to IHG (ΔMAP), indicating that low levels of baseline cardiovagal modulation are related to large exercise pressor reflex responses. This finding confirms the role of vagal modulation in BP responses to isometric contraction in both children and adults. Yet, the relationship between ΔMAP and cardiovagal modulation was no longer significant after controlling for body size (i.e., BSA), suggesting that the influences of baseline cardiovagal modulation upon the exercise pressor response are determined by body size.

Although cardiovagal withdrawal plays an important role at the onset of isometric contraction, activation of the sympathetic nervous system is primarily responsible for the rise in BP during sustained isometric activity [9]. In this study, we did not measure sympathetic nervous system activity, and therefore, we cannot state with certainty

TABLE 3: Cardiovagal modulation and baroreflex sensitivity in response to isometric handgrip exercise.

Parameters	Baseline	Handgrip Exercise	
		Obtained	Adjusted
RR-interval, msec			
Young adults	879 ± 24	743 ± 18*	689 ± 18
Children	727 ± 26	660 ± 20*†	722 ± 19
ln TP, $msec^2$			
Young adults	8.2 ± 0.1	7.6 ± 0.2*	7.4 ± 0.2
Children	8.4 ± 0.1	7.9 ± 0.1*	8.0 ± 0.3
ln HF, $msec^2$			
Young adults	6.1 ± 0.2	6.0 ± 0.2*	6.1 ± 0.3
Children	6.9 ± 0.2	6.3 ± 0.2*†	6.3 ± 0.3
CCV_{HF}			
Young adults	2.7 ± 0.3	3.0 ± 0.3	3.4 ± 0.6
Children	4.8 ± 0.3	3.8 ± 0.4†	3.4 ± 0.7
RMSSD, msec			
Young adults	47.0 ± 5.1	40.4 ± 4.7*	40.6 ± 7.9
Children	64.3 ± 5.9	42.7 ± 5.4*	41.4 ± 8.6
CVS, %			
Young adults	5.2 ± 0.5	5.5 ± 0.7*	5.7 ± 1.2
Children	8.8 ± 0.6	6.4 ± 0.8*†	5.9 ± 1.3
ln BRS, msec/mmHg			
Young adults	2.60 ± 0.09	2.26 ± 0.11	2.38 ± 0.15
Children	2.85 ± 0.10	2.60 ± 0.12	2.44 ± 0.16

Means ± SE. $^*P < .05$, responses to IHG are different from baseline (main effect); $^\dagger P < .05$, task by group interaction.
ln natural logarithm; TP: total power; HF: high frequency; CCV: coefficient of component variance; RMSSD: the square root of the mean of the sum of the squares of differences between adjacent R-R intervals; CVS: coefficient of variation; BRS: baroreflex sensitivity.

what the changes in the integrated function of sympathetic modulation were. The BP response to isometric exercise is often used as an index of sympathetic activation during isometric exercise [10]. Accordingly, our results suggest that since children had a lower pressor response to IHG, greater vagal withdrawal, and similar HR responses compared to adults, they probably experienced less cardiac sympathetic modulation during the exercise stimulus. Conversely, since adults had similar HR increases in response to IHG with children, but smaller reductions in cardiovagal modulation, we can speculate that adults had greater cardiac sympathetic modulation. In other words, adults and children attained similar HR responses during isometric contraction through different mechanisms. Specifically, vagal withdrawal might be responsible for increases in HR in children whereas increases in cardiac sympathetic modulation might be the primary mechanism responsible for the tachycardic response during isometric muscle contraction in adults.

Exploring the contribution of reflex neural mechanisms in pressor response to IHG, previous studies reported that differences in metaboreflex sensitivity could explain the age-group differences in pressor response to exercise. Changes in BP during isometric exercise match the intensity of the exercise stimulus, which is directly related to the active skeletal muscle mass as well as to the relative intensity achieved (%MVC) [29]. In the present study, all subjects performed sustained isometric contraction at the same relative intensity (30% MVC). However, the absolute force held at 30% MVC was different between children and adults (children: 5.86 ± 0.35 kg versus young adults: 16.87 ± 1.22 kg), suggesting that adults used greater muscle mass to achieve the same absolute rate of work with children. Greater muscle mass activation would result in greater increases in BP due to greater metabolite accumulation [30]. Indeed, previous studies have shown that adults have greater blood and muscle lactate concentrations during high-intensity exercise compared to children [23, 24]. In a recent study Turley [11] used postexercise ischemia to activate the metaboreceptors and to assess potential differences in metaboreflex function between children and adults. During the 1st minute of postexercise occlusion, children and adults had a similar drop in BP. The greater accumulation of metabolites in adults compared to children [23, 24] and their similar responses immediately following cuff inflation (i.e., ischemia) [11] suggest a more sensitive metaboreflex in the pediatric subjects. In our study, children had a lower BP response to IHG of same relative intensity compared to adults. If indeed children exhibit a more sensitive metaboreflex, their lower pressor response to IHG may be due to age-related differences in other peripheral reflexes mediating the exercise pressor response, such as the mechanoreflex or baroreflex. To the best of our knowledge, currently there is no research on mechanoreflex function in children and therefore, this statement is purely speculative.

In this study, baroreflex sensitivity was reduced in response to IHG and there were no differences in the magnitude of the response between groups. It has been proposed that during exercise arterial baroreflex is reset to a higher operating point by the action of the central command on the central neuron pool receiving baroreceptor afferents [31]. This adaptation allows for a concomitant increase in HR and BP. During isometric exercise central command may also decrease the gain of the integrated baroreflex, depending on the intensity of the exercise stimulus as well as the size of the active muscle mass [29]. The lack of group differences in BRS responses to IHG could explain the absence of group differences in HR responses to this stimulus. Previous studies have shown that children have lower baseline BRS compared to adolescents and young adults but this was not confirmed by our findings [3]. The relative small sample size in our investigation may explain this discrepancy. It is noteworthy that using spontaneous BP and pulse interval sequences to assess baroreflex sensitivity, we only examined the vagal component of the baroreflex whereas the function of the sympathetic arm of the baroreflex during IHG was not investigated. Age-related differences in the sympathetic component of the baroreflex could explain the lower pressor reflex responses suggestive of lower sympathetic activity during exercise in children compared to the adult group.

It should be noted that peripheral autonomic reflexes are not the only determinants of cardiovascular regulation during isometric exercise. Direct action of the central command descending from the higher motor centers on the cardiovascular control areas is also significantly involved in cardiovascular regulation during isometric exercise [9]. This "feed-forward control" mechanism plays a significant role in cardiovascular adaptations at the onset of exercise and is especially important if only a small muscle mass is activated whereas peripheral autonomic reflexes (i.e., metaboreflex and mechanoreflex) become more important in cardiovascular regulation during continued exertion [9]. To the best of our knowledge, currently, there is no research to investigate potential differences in central command during exercise between children and adults and the present study did not assess the contribution of this mechanism to age-group differences. Therefore, we can only hypothesize that age-related differences in central command activation might contribute to differences in cardiovascular adaptations to IHG between children and adults.

Finally, we demonstrated that ΔMAP was related with the force produced at 30% MVC and that this relationship was independent of body size. Furthermore, the force produced at 30% MVC was the only significant predictor of ΔMAP in the regression analysis. This finding suggests that factors that contribute to force production other than body size (i.e., factors other than the size of muscle mass activated) determine the magnitude of the exercise pressor reflex and may be responsible for the differences in exercise pressor reflex seen between children and adults. For example, the type of muscle fibers recruited during isometric contraction by each age group could influence the magnitude of the pressor response. Previous studies suggested that the exercise pressor reflex is elicited selectively from activation of the fast twitch fibers [32]. Children have lower neuromuscular activation (recruitment and firing rate of motor units) during sustained isometric contraction compared to adolescents and adults [33]. Therefore, children may also have less capability to activate Type II motor units than adults during muscular contractions. Indeed, Halin et al. [34] reported that adults recruited a greater number of Type II fibers during isometric contraction compared to children. According to these findings, the greater pressor response seen in adults in the present study may be attributed to the type of muscle fibers recruited by this group.

5. Limitations

In this study, cardiovagal autonomic regulation was solely assessed with analysis of HR variability. Spectral analysis of HR variability provides information about parasympathetic modulation but does not give us insight into the status of the tonic stimulus [35]. Therefore, our conclusions are limited to the effects of IHG on vagal influences on the modulations of HR. Consequently, inferences cannot be made regarding the tone of the parasympathetic nervous system during IHG. Moreover, we examined the exercise pressor reflex as a whole, involving all peripheral reflexes, and therefore, we cannot draw any conclusions regarding the contribution of each reflex to pressor response. Further, all measures were collected during spontaneous breathing. Respiratory frequencies and tidal volume may affect the HF power of HR variability [36]. Therefore, in adult studies respiration is usually controlled during HR variability measurements by instructing the subjects to breathe at a specific rate. In children, however, uncontrolled breathing may be a better method because it reduces psychological strain [7]. Studies in our laboratory (unpublished data) found that respiratory rate did not significantly change from resting conditions (baseline) to isometric handgrip exercise in middle-aged adults.

In conclusion, the findings of this study suggest that baseline cardiovagal modulation contributes to the magnitude of the pressor reflex response and determines the extent of cardiovagal autonomic adjustments during forearm isometric contraction. Yet, differences in muscle pressor reflex response between children and adults cannot be solely explained by differences in autonomic modulation between groups and appear to be associated with factors determining the absolute force produced during submaximal isometric contraction.

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Clinical Study

Relationships of Cardiorespiratory Fitness with Metabolic Risk Factors, Inflammation, and Liver Transaminases in Overweight Youths

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The aim of this study was to assess the relationships of fatness and fitness with metabolic risk factors, including liver transaminases and inflammation in obese youth, taking in account gender, age, and pubertal stage. 241 children were studied (135 girls), age 11.9 ± 2.2 years ($x \pm$ SD), Body Mass Index z score 5.4 ± 2.7. For girls, VO_{2max} was significantly associated with insulin ($P = .001$), Insulin resistance (HOMA-IR) ($P = .005$), and ALT ($P = .012$); a relationship was displayed between fibrinogen and age and % fat mass (FM) ($P = .008$); for boys, relationships were found between VO_{2max} and diastolic blood pressure and triglycerides; independent associations were also found between age and insulin, HOMA-IR and HDL cholesterol; fibrinogen and sedimentation rate were related ($P \leq .004$) with %FM. Their relationships are observed from young age and increase with the continuous increase of factors. This supports the need to treat overweight as soon as it is detected; improving CRF is one of the ways which could be used to prevent the complications of obesity.

1. Introduction

Overweight is associated with an increased cardiovascular risk, even in youth [1, 2]. It is also associated with a decreased cardiorespiratory fitness (CRF), which is liable to contribute to obesity itself. Several large reports clearly show a relationship between decreased CRF and the occurrence of metabolic risk factors in overweight adults and youth. Whether fitness and fatness have independent influences on metabolic risk, however, is not fully explained [3, 4].

Some of the studies addressed only one individual factor [5–9] but most of them clustered these risks in "metabolic syndrome" (MS) [8, 10–13]; MS usually associates with obesity, dyslipoproteinemia (raised triglyceride and/or reduced HDL-cholesterol levels), hypertension, and insulin resistance or diabetes, but variables included in the MS and their relative weight vary among definitions; the last of them was given by the International Diabetes Federation [14]. Nonalcoholic fatty liver disease is frequently associated with MS, so that it has been proposed as a core feature of it [15, 16]. In addition inflammation is never included in the criteria of MS, while it seems to be involved in the development of its consequences [1, 17].

The value of MS concept itself is still debated [18]. A recent WHO Expert Consultation came to the conclusions that it is not a useful diagnostic or management tool [19].

The present study assessed the respective relationships of CRF and fatness on individual components of MS, including liver transaminases as a surrogate of nonalcoholic fatty liver disease [15, 16]; fibrinogen and sedimentation rate were added as markers of inflammation; CRF was measured by determining the maximal oxygen consumption (VO_{2max}); the marker of overweight was fat mass, instead of BMI, because this latter one is a less valid measurement of body fatness in children and does not discriminate between muscle and fat [20] and it has been shown to be less discriminant than fatness as suggested by a recent report [21]; we took into account the gender and the pubertal development of adolescents, owing to the changes that occur in their lifestyle and hormonal status.

2. Subjects and Methods

The study is part of a research protocol on the genetics of child obesity, which has been approved by the Ethics Committee of the Hôtel Dieu Hospital (Paris); a written consent to the inclusion in the study was given by each child's parents and by adolescents themselves [22].

Subjects were children and adolescents attending the specialized clinic of University Hospital of Caen; they were routinely screened before treatment.

The clinical examination of children was performed by the same clinician. They were all apparently healthy with no obvious endocrine disease. Pubertal stage was assessed according to Tanner criteria [23]. Weight was assessed with an electronic beam balance; height was measured twice by the same examiner to the nearest 0.5 cm. Body mass index (BMI) was calculated (kg/m^2). Patients were considered as overweight when their BMI was over 2 SD of the available French charts [24], which fit better with the local population than the IOTF charts; data were also compared with IOTF cut off points [25]. Blood pressure (BP) was measured by an automatic device on a sitting patient, at least twice, at the end of a consultation (Agilent A1; Agilent 91745 Massy France).

Blood sample was drawn after an overnight fast, for measurements of plasma glucose, insulin, triglycerides, HDL and LDL cholesterol, alanine aminotransferase (ALT), aspartate aminotransferase (AST), sedimentation rate and fibrinogen. Homeostasis model assessment-insulin resistance (HOMA-IR) was calculated as a measure of insulin resistance (insulin (mU/L) $*$ plasma glucose (mmol/L)/22.5).

Body composition (total and relative (%) fat and fat-free mass) was measured by X-ray absorptiometry (DEXA) (HOLOGIC QDR-4500 A) [26].

VO^{2}Max was measured by a previously validated protocol reported [26]; it was adapted from Achten [27]; the use of this graded exercise to exhaustion gives an exact value of the peak VO^2 [26, 27]; subjects performed a graded exercise on a bicycle ergometer (ERGOLINE 500, Bosch) linked to a gas analyzer (Ergocard SCHILLER). Before the test, the children were given several minutes to familiarise themselves with the ergometer and to adapt to the valve/mouthpiece. The subjects warmed up for 5 minutes at 0 W. The first step was fixed at 30 W with a rectangular progression of 20 W every 3 minutes 30 seconds, until exhaustion.

2.1. Statistical Analysis. Results were expressed as mean ± 1 SD; statistical analysis used univariate regression analysis between VO_{2max} and anthropometric and biologic data; multivariate analyses performed on each gender; they used age and % fat mass as covariates of VO_{2max}. Tanner stage was also tested as covariate.

The level of significance was set at $P < .05$.

Table 1: Descriptive data.

		Girls		Boys	
	Unit	*X*	*SD*	*x*	*SD*
N		135		106	
Age	Years	11.9	2.3	12.1	2.3
Tanner		3.0	1.8	2.0	1.3
Weight	k	62.4	16.8	69.0	21.2
Height	m	1.52	0.11	1.55	0.12
BMI	k/m^2	26.7	4.5	28.1	5.8
z Score BMI		5.1	2.5	5.8	2.9
Overweight (IOTF cut off points)	%	47		37	
Obesity (IOTF cut off points)	%	53		63	
Fat Free Mass	%	56.6	6.4	57.6	6.8
Fat Mass	%	40.6	6.4	39.3	6.6
$VO_{2\,max}$	mL O^2/k/min	25.5	5.1	27.9	6.1
Systolic BP	MmHg	116	19	120	13
Diastolic BP	MmHg	61	12	65	10
Fasting Glucose	mmol/L	4.7	0.4	4.9	0.4
Fasting Insulin	mU/L	10.4	5.4	10.9	7.2
HOMA-IR		2.1	1.1	2.4	1.7
HDL Cholesterol	Mmol/L	1.5	0.4	1.4	0.3
LDL Cholesterol	mmol/L	2.8	0.9	2.7	1.3
Triglycerides	mmol/L	0.8	0.4	0.9	0.5
AST	IU/L	23	8	24	7
ALT	IU/L	24	7	28	17
Sedimentation rate		13	6	12	7
Fibrinogen	g/L	3.6	0.8	3.6	0.7

3. Results

241 children were studied (135 girls), aged 11.9 ± 2.2 years (x ± SD), range: 6.2 ± 17.9; their BMI z score was 5.4 ± 2.7.

Descriptive data are given in Table 1.

Univariate regressions (Table 2) displayed significant relationships between VO_{2max} and age, pubertal development, BMI, body composition parameters, insulin and HOMA-IR, lipids and ALT (≤0.02), and inflammation parameters ($P \leq .0005$).

Table 3 shows the results of multivariate regression analysis. Since Tanner stage did not enter in any model, it was discarded from analysis. For girls, $VO_{2\,max}$ remained significantly associated with insulin ($P = .001$), HOMA-IR ($P = .005$), and ALT ($P = .012$); a relationship was displayed between fibrinogen and age and % fat mass ($P = .008$); for boys, relationships were found between VO_{2max} and diastolic BP and triglycerides; independent associations were also found between age and insulin, HOMA-IR, and HDL cholesterol; fibrinogen and sedimentation rate were related ($P \leq .004$) with %FM.

Table 2: Univariate regression analysis between VO_{2max} and metabolic risk factors.

	P	F	T
Age	.0062	7,64	−2.976
Tanner stage	.0018	10.043	−3.169
BMI	<.0001	83.809	−9.55
z score	<.0001	48.949	−6.99
Fat Free Mass kg	.0002	14.576	−3.818
Fat Free Mass %	<.0001	43.856	6.622
Fat Mass kg	<.0001	92.285	−9.761
Fat Mass %	<.0001	56.838	−7.539
Systolic BP	.124		
Diastolic BP	.072		
Fasting Glucose	.220		
Fasting Insulin	<.0001		−5.52
HOMA-IR	<.0001		−4.98
Triglycerides	.010		−2.59
HDL Cholesterol	.019		2.36
LDL Cholesterol	.509		
AST	.770		
ALT	.0007		−3.421
Sedimentation rate	.0002	14.26	−3.776
Fibrinogen	.0005	8.012	−2.831

4. Discussion

CRF and adiposity are associated with metabolic risk factors and cardiac and vascular risks; it is known that these risks are already present in youth [2, 28]. The main roles are attributed either to fitness or fatness [3, 8]. In fact an influence of both variables could be expected owing to the relationships between obesity and movement efficiency [29] which lately led to social exclusion, but differences in statistical analysis, ways of assessing metabolic risk, adiposity, and/or taking account of gender and sexual development could explain at least part of these discrepancies.

The potential metabolic interdependence between these risks lead to the concept of metabolic syndrome. Currently this concept is debated [18, 19], and these risk factors could have only statistical relations. So studying the individual relationships between each of them and with fitness or adiposity could be of interest to understand the mechanisms involved in the health risks of obesity; it could also give more specific aims to improve the efficiency of prevention campaigns [30].

The present study showed mainly a relation between CRF (VO_{2max}) and insulin metabolism in girls; VO_{2max} was significantly related to diastolic BP in boys and to ALT in girls. Age was mainly involved in the relationships with insulin and lipids in boys and with inflammation in girls. Apart from the relationship between inflammation parameters in boys, the degree of adiposity did not appear to play a main influence on the early occurrence of risk factors. None of these relationships depended on pubertal development.

It seemed useful to address current adiposity and not only BMI which is the sum of fat free and fat mass [20]; a previous study shows that measured fat mass is a better variable to assess the metabolic risk of obesity, owing to the endocrine and inflammatory actions of adipose tissue [1, 21]; most of the studies use BMI as marker of adiposity [13]; their conclusions could be taken with caution since an increased BMI can be associated with an increased muscle mass, specifically in active boys.

Subjects of the present study did not fulfil the criteria of metabolic syndrome, whatever the definition used; it is known that the risk of developing MS factors increases with the degree of overweight [1, 10, 18]. In some reports, the relationships between MS and CRF only occur at high degrees of adiposity [9]. Our regression analysis showed a direct effect of age on inflammation and lipoproteins, from young age and from a moderate degree of excess adiposity; these observations, added to the early development of arterial dysfunction [28] and the relationship between child obesity and its complications in adult [31], support a precocious treatment of overweight in youth.

When it is assessed, no effect of pubertal status is observed [9].

Differences were found between boys and girls in the relationships between risk factors (lipid profile, insulin resistance) and fitness by some authors [7, 32, 33] and not by others [9]; such differences were expected, due to the difference in insulin sensitivity between both sexes [34]. They should not result from sex hormones, since no effect of pubertal stage was found; more differences are found in lifestyle; boys are more active than girls, and physical activity affects all cardiovascular risks [7, 17].

Imperatore finds a significant association between insulin sensitivity and CRF only in boys [7]; however, since only BMI was measured, this association could have resulted from a higher muscle mass in boys rather than from an increased adiposity; the relationship between fasting glucose and CRF disappears when body fat is taken into account; in the same report, HOMA and fasting glucose are negatively associated with CRF only in the higher body fat tertile [9]; Gutin finds also a relationship between VO_{2max} and the percentage of body fat mass [21, 32] while others find no relationship between VO_{2max} and insulin sensitivity [11]. CRF could interact with metabolic risk factors through insulin resistance. Insulin resistance is reported as the key mechanism in the development of metabolic complications of obesity [1], yet these models usually do not take physical activity or CRF into account. Physical training enhances insulin sensitivity in the exercised muscle and enhances muscle contraction-induced glucose uptake in the muscle; the mechanisms include postreceptor insulin signalling, increased glycogen synthesis, and enhanced muscle capillarization and blood flow [35].

Obesity is a low-grade inflammation disease, positively associated with body fat and negatively with CRF [9]; this inflammation, yet not included in MS criteria, is a possible pathway in its pathogenesis: it induces insulin resistance and MS; insulin resistance promotes inflammation further through an increase in free fatty acids [17].

Table 3: Multivariate regression between metabolic risk factors and VO^2Max, using age and % fat mass as covariates.

	Girls			Boys		
	F	P		F	P	
Systolic BP	1.938	.129		2.508	.066	
Diastolic BP	0.201	.896		3.294	.025	VO^2Max: 0.048
Fasting Glucose	1.476	.226		1.968	.125	
Fasting Insulin	5.683	.001	VO^2Max: 0.002	6.317	<.0001	Age: 0.017
HOMA-IR	4.530	.005	VO^2Max: 0.001	6.275	<.0001	Age: 0.026
Triglycerides	2.384	.073		3.976	.010	VO^2Max: 0.034
HDL Cholesterol	1.055	.371		3.139	.029	Age: 0.039
LDL Cholesterol	0.846	.472		0.930	.431	
AST	1.051	.373		0.514	.674	
ALT	3.829	.012	VO^2Max: 0.073	2.492	.065	
Fibrinogen	4.21	.008	Age: 0.040 % FM: 0.007	2.938	.038	%FM: 0.018
Sedimentation rate	4.077	.009		4.085	<.001	%FM: 0.045

Tanner stage did not significantly enter in any model tested.

The increase in liver transaminases is associated to other components of MS, particularly to insulin resistance [15, 16, 33, 36]; the precise relationship between fatty liver and MS is not precisely known but is likely to also involve insulin resistance [37, 38]; in addition, the present study shows that it is under regulation of CRF, such as other risk factors [38].

So far, no specific treatment of nonalcoholic fatty disease has been proposed [39]; it is known that weight loss improves liver dysfunction [32, 33]; the present observation suggests that lifestyle interventions aimed at enhancing CRF should also be efficient in improving liver parameters.

5. Conclusions

CRF is one of the parameters associated with individual metabolic risk factors in young overweight subjects, together with age and percentage of fat mass. As expected, the main relationship was found with insulin resistance. CRF was also associated with other variables often associated with metabolic risk of obesity, that is, transaminases and inflammation.

The relationships differed between boys and girls and were not influenced by their pubertal stage. They were observed from young age and increased continuously with the factors studied.

This supports the need to treat overweight as soon as it is detected; improving CRF is one of the ways which could be used to prevent the complications of obesity.

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Review Article

Review of Prediction Models to Estimate Activity-Related Energy Expenditure in Children and Adolescents

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Purpose. To critically review the validity of accelerometry-based prediction models to estimate activity energy expenditure (AEE) in children and adolescents. *Methods*. The CINAHL, EMBASE, PsycINFO, and PubMed/MEDLINE databases were searched. Inclusion criteria were development or validation of an accelerometer-based prediction model for the estimation of AEE in healthy children or adolescents (6–18 years), criterion measure: indirect calorimetry, or doubly labelled water, and language: Dutch, English or German. *Results*. Nine studies were included. Median methodological quality was 5.5 ± 2.0 IR (out of a maximum 10 points). Prediction models combining heart rate and counts explained 86–91% of the variance in measured AEE. A prediction model based on a triaxial accelerometer explained 90%. Models derived during free-living explained up to 45%. *Conclusions*. Accelerometry-based prediction models may provide an accurate estimate of AEE in children on a group level. Best results are retrieved when the model combines accelerometer counts with heart rate or when a triaxial accelerometer is used. Future development of AEE prediction models applicable to free-living scenarios is needed.

1. Introduction

Physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure (EE) [1]. Research has shown that there is a positive relationship between physical activity and health-related fitness [2, 3]. Health-related fitness refers to those components of fitness that benefit from a physically active lifestyle and relate to health [4]. The relationships between physical activity, health-related fitness, and health status are described by Bouchard et al. [4].

Valid and reliable instruments are necessary, when examining the dose-response relationship between physical activity and health-related fitness [5].

Estimation of physical activity and energy expenditure in children is difficult since children show physical activities of varying intensity and short of duration [6]. Subjective techniques are less preferable in children because of their complex movement behavior and their ability to accurately recall intensity, frequency, and duration of their activities [5].

Direct observation is considered a gold standard for the assessment of physical activity. Gold standard methods to assess activity related energy expenditure (AEE) are doubly labelled water and indirect calorimetry [5, 7]. These methods are mainly used for calibration and validation of objective and subjective measurements in laboratory and field settings. Due to their costs and invasiveness are these methods less suitable for population-based studies [5, 7]. There is a need for accurate, objective, and cost-effective methods to asses AEE in children in free-living situations.

Accelerometry is objective as well as cost-effective and less invasive. Accelerometers have evolved from simple mechanical instruments to electronically three-dimensional instruments to assess physical activity and energy expenditure. An accelerometer estimates accelerations produced by movement of a body segment or limb parts [8]. Acceleration is the change in velocity over time of the body part as it moves. Electronic transducers and microprocessors convert recorded accelerations into digital signals, which are the "counts". In research, the counts can be used as an estimation of physical activity. Prediction models convert these counts in EE or AEE [8]. AEE can be derived from EE by subtracting resting energy expenditure (REE). Researchers and clinicians prefer predicting AEE instead of gross EE because REE can vary with age, maturation, body mass and level of physical activity [9].

In literature different prediction models are described to assess AEE in children and adolescents. The aim of this study is to review the validity and generalizability of accelerometry based prediction models to estimate AEE in children and adolescents.

2. Method

2.1. Literature Search. Electronic bibliographic databases CINAHL, EMBASE, PsycINFO, and PubMed/MEDLINE were searched till April 2009. The following MeSH terms and text words were used: child*, adolescent*, youth, physical activity, energy expenditure, accelerometer, accelerometers, accelerometry, uniaxial accelerometer, biaxial accelerometer, triaxial accelerometer, motion sensor, motion sensors, activity monitor, activity monitors, validity, validation, equation, prediction model, calibration, and reproducibility of results.

Studies (written as full reports) were included in this review if their main purpose was to develop and/or validate an accelerometry based prediction model for the estimation of AEE in healthy children and/or adolescents (6–18 years). The AEE predicted by the model, had to be compared with a criterion measure of AEE as doubly labelled water or indirect calorimetry. Studies written in Dutch, English, and German were included. Studies concerning pedometers were excluded.

One researcher (SdG) performed the search strategy. The first selection regarding relevance, based on title and abstract, was performed by two independent researchers (SdG and MS). Furthermore, the included articles were judged on full-text by these two independent researchers. References of the included articles were screened for additional eligible studies.

2.2. Data Extraction. To evaluate and compare the studies, data were extracted. Two reviewers independently extracted the data (SdG and MS). Disagreements between the two reviewers regarding a study's eligibility were resolved by discussion until consensus was reached or, when necessary, a third person (JdG) acted as adjudicator.

The data extraction was based on items that have an impact on the range and generalizability of a prediction model according to Puyau et al. [10] and Trost et al. [11]. These items were age range, setting, type of activities, and localisation of the accelerometer. Additionally accelerometer type, criterion measure, prediction models, and conclusions were extracted.

2.3. Evaluation. An existing checklist [12] was modified to evaluate and compare the studies regarding methodological issues (see Appendix A). Checklist items included study design, validity, reliability, and feasibility. Maximum possible score was 10, high score reflected a better methodological quality. Two reviewers independently scored all included studies on the checklist (SdG and MS). A third reviewer (JdG) was consulted when the reviewers did not reach consensus.

3. Results

3.1. Search Result. The literature search identified 438 studies, after judgement based on title and abstract 39 studies remained (see Figure 1). Twenty studies were excluded after reading the full text due to deviating main purposes. Four studies were excluded because the population did not consist of healthy children aged 6–18 year. Six studies were excluded because the predicted AEE was not compared to a criterion measure of AEE as doubly labelled water or indirect calorimetry. Finally, one study was not published as an article but as a dissertation and therefore excluded.

In total eight studies were selected as eligible [10, 11, 13–18]. One additional study was not retrieved in the databases, it was already in possession of the author [9]. Therefore this review included nine studies describing the validation and generalizability of prediction models for the assessment of AEE in children and adolescents (see Appendix B).

All included studies had a cross-sectional research design. In total twenty-eight different prediction models were described. Two studies assessed the generalizability of previously published prediction models [11, 14]. In eight studies new prediction models were derived [9, 10, 13–18]. Some authors performed additionally a cross-validation analysis to assess the reliability of the new retrieved prediction model [13–15, 18]. Two studies retrieved data free-living with doubly labelled water as a criterion measure [11, 14]. The remaining studies [9–11, 13, 14, 18] were set in a controlled laboratory environment and used portable indirect calorimetry equipment as criterion measure, Puyau et al. [10, 17] additionally used room respiration calorimetry.

The included studies described six different accelerometers; two omnidirectional (Actical, Actiwatch), two uniaxial (Actigraph/CSA, Caltrac) and one triaxial (RT3). For the Actiheart this property could not be retrieved from the included studies.

The score on the checklist regarding methodological issues ranged from 5.0 to 8.0 (median 5.5 ± 2.0 IR). None of the included studies reported the amount of missing/lost data due to (malfunctioning of) the motion sensor, or

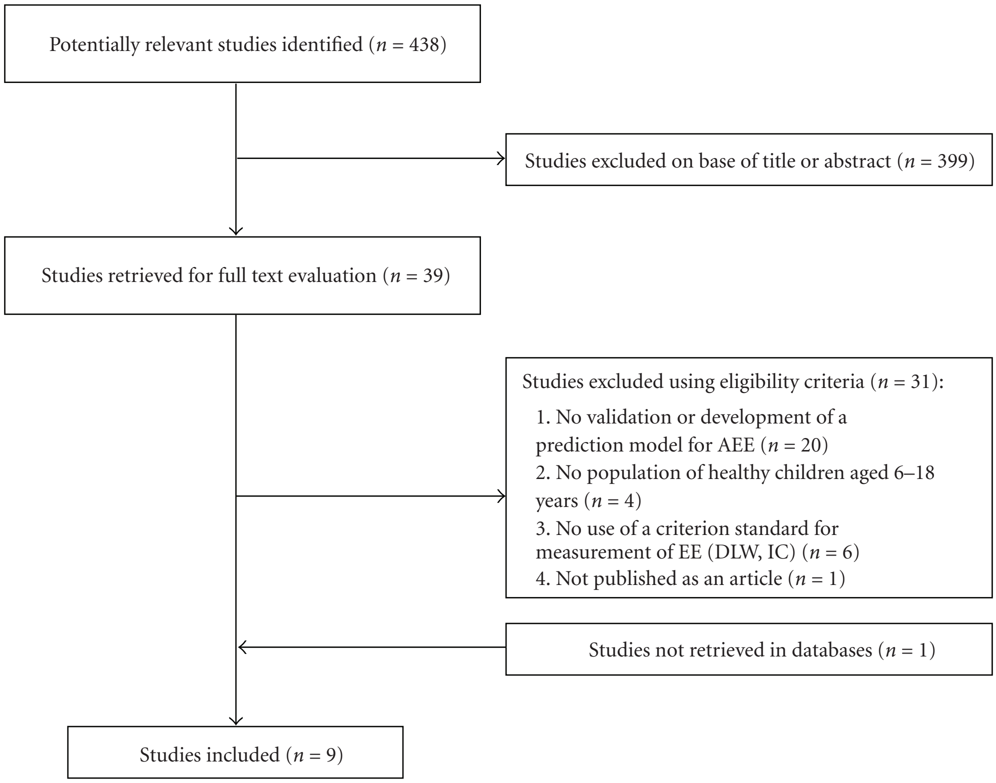

Figure 1: Selection process for studies included in the review.

refusal rate or the compliance rate of wearing the motion sensor. Due to this no conclusions could be made regarding feasibility. To review the validity and generalizability of the prediction models, the models were ordered in a table by accelerometer (see Table 1).

3.2. Validity. Eleven prediction models regarding the Actical were derived in laboratory settings based on activities as handwriting, cleaning, playing a video game/Nintendo, and walking at different speeds and grades (treadmill and indoor track) [9, 10, 13]. R^2 ranged from 0.45 to 0.81 (mean 0.65), which indicates that the prediction models explained 45–81% of the variance in measured AEE. The model of Puyau et al. [10] explained the largest variance (81%) with a standard error of the estimate (SEE) of 0.0111 ($\text{kcal} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). This model was derived during activities as playing Nintendo, cleaning, treadmill walking, and running. The model included age, gender, and the counts of the Actical placed at the hip. Puyau et al. [10] concluded that this model provided a valid measurement of AEE on a group level, further development was needed to accurately predict AEE of individuals.

For the Actigraph/CSA accelerometer, seven models were derived. One model was based on free-living data compared to doubly labelled water [15]. Six models were based on data retrieved during activities as lying, sitting, Nintendo, arts and crafts, playing, and walking at different speeds and grades (treadmill) [13, 14, 17]. R^2 ranged from .37–.87. The prediction model of Corder et al. [14] explained with 87% the largest variance in measured AEE with a root mean square error (RMSE) of $118.0\,\text{J} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. This model contained accelerometer counts of the Actigraph placed at the hip, and height (cm) of the child. This model was derived during various intensity activities like lying, sitting, slow and brisk walking, jogging and hopscotch. The study by Corder et al. [14] compared models based on accelerometer counts solely and models that combined accelerometer counts with heart rate. The authors concluded that the combined models may be more accurate and widely applicable than those based on accelerometers alone.

The model by Ekelund et al. [15], derived during free living activities (fourteen consecutive days) explained 45% of the variance in measured AEE. There was a mean difference of $-45\,\text{kcal} \cdot \text{d}^{-1}$ with large limits of agreement; -485 to $395\,\text{kcal} \cdot \text{d}^{-1}$.

The studies of Corder et al. [13, 14] derived six prediction models for the Actiheart, one model (Actiheart Activity) did not contain heart rate, the remaining five combined heart rate and activity counts. R^2 ranged from 0.69–0.91. The explained variance in measured AEE was the lowest for the Actiheart Activity model without heart rate (69%). The range of R^2 of the five models including heart rate was 0.86–0.91, thus an explained variance in measured AEE of 86–91%. The model with the largest explained variance (91%) consisted of heart rate, counts, and gender (RMSE $97.3\,\text{J} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). The derivation activities were lying, sitting, slow and brisk walking, jogging and hopscotch. Additionally a step test was performed for calibration. Despite systematic

Table 1: Prediction models ordered by accelerometer.

Accelerometer	Activities	Criterion	Prediction models & Statistics
Actical (Mini Mitter Co., Inc., Bend, OR), (formerly known as Actiwatch). Omnidirectional: senses motions in all directions but is most sensitive within a single plane. Detects low frequency (0.5–3.2 Hz) G-forces (0.05–2.0 Hz) common to human movement and generates an analogue voltage signal, that is, filtered and amplified before being digitized by an A-to-D converter at 32 Hz.	Flat walking, graded walking, and running on a treadmill.	Indirect calorimetry	Corder et al. [13] AEE ($J \cdot kg - 1 \cdot min^{-1}$) = 0.2AC + 168.7 → R^2 = 0.67, SEE 105 Flat walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) −65 ± 23, 95% CI −78, −52 Graded walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) 72 ± 35, 95% CI 52, 91 Running: Mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) 18 ± 69, 95% CI −26, 62 Flat and graded walking significantly different from measured values.
The digitized values are then summed over user-specified time intervals (epoch) between 0.25 and 1 min. The actual numbers stored by the Actical are proportional to the magnitude and duration of the sensed accelerations and, thus, roughly correspond to changes in physical activity energy expenditure. When mounted to the hip, most sensitive to vertical movements of the torso. Water resistant, lightweight (17 g), small ($2.8 \times 2.7 \times 1.0\ cm^3$).	- Three sitting activities: handwriting, card sorting, and Video game playing. - Three simulated house cleaning activities: floor sweeping, carpet vacuuming, table dusting. and - Locomotion activities: slow and moderate treadmill walking, treadmill jogging, OR self-paced slow walking, self-paced fast walking (indoor track).	Indirect calorimetry	Heil et al. [9], 1R = single regression modelling, 2R = double regression modelling Include sitting and cleaning activities Ankle 2R: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.02304 + (3.750E-5) × AC → R^2 =.60, SEE = 0.020, $P < .001$ Hip 2R: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.01667 + (5.103E-5) × AC → R^2 =.75, SEE = 0.014, $P < .001$ Wrist 2R: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.01149 + (3.236E-5) × AC → R^2 =.59, SEE = 0.020, $P < .001$ Include all activities Ankle 1R: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.03403 + (1.179E-5) × AC → R^2 =.45, SEE=0.028, $P < .001$ Hip 1R: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.03411 + (1.270E-5) × AC → R^2 =.61, SEE=0.024, $P < .001$ Wrist 1R: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.02299 + (1.902E-5) × AC → R^2 =.67, SEE=0.022, $P < .001$ Include walking and jogging activities Hip 2R: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.03534 + (1.135E-5) × AC → R^2, SEE = 0.018, $P < .001$ Include walking activities only Ankle 2R: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = −0.02268 + (1.939E-5) × AC → R^2 =.60, SEE = 0.015, $P < .001$ Wrist 2R: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.03115 + (1.581E-5) × AC → R^2 =.69, SEE = 0.019, $P < .001$
	Playing Nintendo, using a computer, cleaning, aerobic exercise, ball toss, treadmill walking, and running.	Room respiration calorimetry 4 h, Indirect calorimetry 1 h.	Puyau et al. [10] Hip: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$)=0.00423+0.00031*$Actical^{0,653}$ → R^2 0.811, SEE 0.0110 Counts, age, and gender were included in the model; inclusion of height gave no significant improvement.

Table 1: Continued.

Accelerometer	Activities	Criterion	Prediction models & Statistics
ActiGraph (model 7164, formerly known as Computer Science and Applications *CSA* activity monitor. Manufacturing Technologies Inc. health Systems, Shalimar, FL) Uniaxial. Is sensitive to movements in the 0.51–3.6 Hz range. Hip- and ankle-mounted. When mounted to the hip, most sensitive to vertical movements of the torso. The acceleration signal is represented by an analog voltage that is sampled and digitized by an eight-bit analog-to-digital converter at a rate of 10 times per second.	Flat walking, graded walking, and running on a treadmill.	Indirect calorimetry	Corder et al. [13] Hip: AEE ($J \cdot kg^{-1} \cdot min^{-1}$) = 0.17 counts + 201.1 → $R^2 = 0.5$, SEE 123 Flat walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) −88 ± 14, 95% CI −97, 80 Graded walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) 66 ± 26, 95% CI 51,82 Running: Mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) 139 ± 60, 95% CI 101, 177 All significantly different from measured values. Ankle: AEE ($J \cdot kg^{-1} \cdot min^{-1}$) = 0.89 counts + 39.4 gender – 1.4 height + 361.9 → $R^2 = 0.37$, SEE 144 Flat walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) −104 ± 39, 95% CI −126, −82 Graded walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) 77 ± 48, 95% CI 51, 103 Running: Mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) 176 ± 233, 95% CI 28, 324 All significantly different from measured values. Age was not included in the models because of lack of heterogeneity in the sample.
	Six activities, each activity lasted 5 minutes: Lying, sitting, slow walking, brisk walking, jogging, hopscotch. (Step test calibration 8 minutes).	Indirect calorimetry	Corder et al. [14] validation of priori models and one new model derived. Corder et al. [13], hip: AEE ($J \cdot kg^{-1} \cdot min^{-1}$) = 0.054 × AC[counts per minute] + 169 → $R^2 = 0.81$, RMSE = 161.8 Mean bias: −44.8; 95% CI: −54.1, −35.5 Derivation activities: flat and graded treadmill walking and flat running Puyau et al. [17], hip: AEE ($J \cdot kg^{-1} \cdot min^{-1}$) = 0.042 × AC[counts per minute] + 76.6 → $R^2 = 0.84$, RMSE = 245.3 Mean bias: −151.6; 95% CI: −160.4, −142.8 Derivation activities: various sedentary, light, moderate, and vigorous activities Trost et al. [19], hip: AEE ($J \cdot kg^{-1} \cdot min^{-1}$) = 3.35 × AC[counts per minute] + 334.8 × weight [kg] − 9334 → $R^2 = 0.85$, RMSE = 126.0 Mean bias: 5.5; 95% CI: −3.6, 14.6 Derivation activities: flat treadmill activity at 3.2, 6.4, and 9.6 km^{-1} Corder et al. [14], hip: AEE ($J \cdot kg^{-1} \cdot min^{-1}$) = 0.1 × AC[counts per minute] − 2.29 × height [cm] + 353 → $R^2 = 0.87$, RMSE 118.0 Mean bias −1,9; 95% CI −11.4, 7,6 Derivation activities: lying, sitting, slow and brisk walking, jogging and hopscotch
	Free-living; Two school weeks, 14 consecutive days, the children wore the monitor during daytime following their normal living. Exceptions were during water activities such as swimming and bathing.	Doubly labelled water	Ekelund et al. [15] Centre of gravity/lower back: AEE ($kcal \cdot d^{-1}$) = (Activity counts × 1.042) − (Gender × 243.4) + 238 → Adjusted $R^2 = 0.45$, SEE 149 The mean difference between measured and predicted AEE was −45 $kcal \cdot d^{-1}$ ($P = .58$), and the 95% limits of agreement were −485 $kcal \cdot d^{-1}$ to 395 $kcal \cdot d^{-1}$.

Table 1: Continued.

Accelerometer	Activities	Criterion	Prediction models & Statistics
	Sedentary: Nintendo, arts and crafts, playtime 1 Light activities: aerobic warm-up, walk 1 Moderate activities: Tae Bo exercises, playtime 2, walk 2 Vigorous activity: jogging.	Room respiration calorimetry	Puyau et al. [17] Hip: AEE (kcal/kg/min) = 0.0183 + 0.000010 (counts) → SEE 0.0172 → r^2 (adj) 75% Fibula head: AEE (kcal/kg/min) = 0.0142 + 0.000007 (counts) → SEE 0.0154 → r^2 (adj) 82% Predicting AEE from the combination of the counts from the hip and leg increased the r^2 (adj) to 86%. Regression of AEE on counts was independent of gender and age, thus only counts were included in the model.
	Field conditions; flat oval indoor track. Normal walking, brisk walking, easy running, fast running. The intensity of each task was self-selected.	Indirect calorimetry	Trost et al. [11] validation of Puyau et al. 2002 Puyau et al. [17], hip: AEE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.0183 + 0.000010 (counts per minute)*t*-tests for difference in means of measured AEE (indirect calorimetry) and predicted AEE by Puyau equation: Normal walking: 0.6% not significantly different (pure error 0.014 $kcal \cdot kg^{-1} \cdot min^{-1}$) Brisk walking −13.3% significantly different (pure error 0.025 $kcal \cdot kg^{-1} \cdot min^{-1}$) Slow running −29.3% significantly different (pure error 0.054 $kcal \cdot kg^{-1} \cdot min^{-1}$) Fast running −37.7% significantly different (pure error 0.078 $kcal \cdot kg^{-1} \cdot min^{-1}$) Overall mean pure error was 0.049 $kcal \cdot kg^{-1} \cdot min^{-1}$ Mean bias on ratio scale is 1.33, difference between measured and predicted AEE was +33%. The corresponding 95% ratio limits of agreement were 0.44–2.22
Actiheart (Cambridge Neurotechnology, Cambridge, UK). Combined HR and movement sensor is able to measure acceleration, HR, HR variability, and ECG magnitude. Acceleration is measured by a piezoelectric element with a frequency range of 1–7 Hz (3 dB). One electrode is placed at the base of the child's sternum and the other horizontally to the child's left side. The main component is 7 mm thick with a diameter of 33 mm. A wire of approximately 100 mm length runs to the clip ($5 \times 11 \times 22\ mm^3$). The total weight is 8 g.	Flat walking, graded walking, and running on a treadmill (protocol).	Indirect calorimetry	Corder et al. [13] Actiheart Activity, chest: AEE ($J \cdot kg^{-1} \cdot min^{-1}$) = 0.22 counts + 29.3 gender + 144.3 → $R^2 = 0.69$, SEE 101 Flat walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) −74 ± 32, 95% CI −91,−56 Graded walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) 56 ± 32, 95% CI 38, 74 Running: Mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) −86 ± 116, 95% CI −159, −12 All significantly different from measured values. Actiheart Combined, chest: AEE ($J \cdot kg^{-1} \cdot min^{-1}$) = 4.4 HRAR + 0.08 counts − 2.7 gender + 1.1 (gender × HRAR) + 15.1 (HRAR: Heart Rate Above Rest) → $R^2 = 0.86$, SEE 69 (69 $J \cdot kg^{-1} \cdot min^{-1}$) Flat walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) −11 ± 27, 95% CI −55, −15 Graded walking: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) −38 ± 48, 95% CI −29, 26 Running: mean difference ($J \cdot kg^{-1} \cdot min^{-1}$) 10 ± 102, 95% CI −105, −6 Graded walking significantly different from measured values. (Age was not included in the models because of lack of heterogeneity in the sample).

Table 1: Continued.

Accelerometer	Activities	Criterion	Prediction models & Statistics
	Six activities, each activity lasted 5 minutes: Lying, sitting, slow walking, brisk walking, jogging, hopscotch. (Step test calibration 8 minutes).	Indirect calorimetry	Corder et al. [14] validation of priori models and new models derived. Corder et al. [13], chest: HR + ACC model: AEE $(J \cdot kg^{-1} \cdot min^{-1})$ = 5.6 × HRaS [bpm] + 1.37 × gender*HRaS + 0.1 × AC[counts per minute] − 44 × gender − 129 (HRaS: Heart Rate above Sleep) → $R^2 = 0.90$ RMSE = 118.0 Mean bias: 18.7; 95% CI: 8.1, 29.3 Derivation activities: flat and graded treadmill walking and flat running Corder et al.[13]/Branched, chest: HR equation: AEE $(J \cdot kg^{-1} \cdot min^{-1})$ = 6.2 × HRaS [bpm] – 27 × gender + 1.2 × gender*HRaS– 139 AC equation: AEE $(J \cdot kg^{-1} \cdot min^{-1})$ = 0.22 × AC[counts per minute] + 29 × gender + 144 $R^2 = 0.90$, RMSE = 115.6 Mean bias: −43,4; 95% CI: −52.2, −34.6 Derivation activities: flat and graded treadmill walking and flat running (First branch threshold is 25 activity counts per minute, the second depends on the HRaS) Corder et al. [14], chest: AEE $(J \cdot kg^{-1} \cdot min^{-1})$ = 5.17x HRaS [bpm] + 0.61 × gender*HRaS + 0.07 × AC[counts per minute] −0.6 × gender − 74 → $R^2 = 0.90$, RMSE = 100.1 Mean bias −2.5; 95% CI: −12.2, 7.2 Derivation activities: lying, sitting, slow and brisk walking, jogging and hopscotch Corder et al. [14], chest: AEE $(J \cdot kg^{-1} \cdot min^{-1})$ = 3.95 × HRaS[bpm] + 0.26 × gender*HRaS + 0.07 × AC[counts per minute] + 8 × gender + 0.68 ×α-step + 1.31 × β-step* HRaS −49 $R^2 = 0.91$, RMSE = 97.3 Mean bias: −2.3; 95%CI: −11.4, 6.8 Derivation activities: Lying, sitting, slow and brisk walking, jogging and hopscotch (with step calibration)
Actiwatch (model AW16; Mini-Mitter, Bend Or). Omnidirectional accelerometer built from a cantilevered rectangular piezoelectric bimorph plate and seismic mass, which is sensitive to movement in all directions, but most sensitive in the direction parallel with the longest dimension of the case. Is designed to detect a wide range of limb movements related to sleep/wake behavior. Sensitive to movements in the 0.5- to 7-Hz frequency range. Firmware detects the peak value of 32 samples in a 1-s window and adds this to the accumulated value for that epoch. Waterproof.	Sedentary: Nintendo, arts and crafts, playtime 1 Light activities: aerobic warm-up, walk 1 Moderate activities: Tae Bo exercises, playtime 2, walk 2 Vigorous activity: Jogging.	Room respiration calorimetry	Puyau et al. [17] Hip: AEE $(J \cdot kg^{-1} \cdot min^{-1})$ = 0.0144 + 0.000038 hip (counts) → SEE 0.0147 → r^2(adj) 81% Fibula head: AEE $(J \cdot kg^{-1} \cdot min^{-1})$ = 0.0143 + 0.000020 leg (counts) → SEE 0.0195 → r^2(adj) 71% Predicting AEE from the combination of the counts from the hip and leg increased the r^2(adj) to 84%. Regression of AEE on counts was independent of gender and age, thus only counts were included in the model.
	Playing Nintendo, using a computer, cleaning, aerobic exercise, ball toss, treadmill walking and running.	Room respiration calorimetry 4 h, Indirect calorimetry 1 h.	Puyau [10] Hip: AEE $(kcal \cdot kg^{-1} \cdot min^{-1})$ = 0.00441 + 0.00032*Actiwatch^{0,724} → r^2 0.79, SEE 0.0117 Counts, age and height were included in the model, inclusion of gender gave no significant improvement.

Table 1: Continued.

Accelerometer	Activities	Criterion	Prediction models & Statistics
Caltrac accelerometer (Muscle Dynamics Fitness, Madison, Wis, USA). Measures the degree and intensity of movement in the vertical plane.	Free-living; Three days, including one weekend day. The subjects began wearing the Caltrac upon waking in the morning and continued until just before going to sleep at night. The Caltrac was taken off for activities involving water, such as swimming or bathing.	Doubly labelled water	Johnson et al. [16] Hip: AEE (kcal · d) = 63.97+ (284.962 × gender) − (17.671 × race) + (12.876 × FM) − (6.18 × FFM) → R^2 = 0.28, P = .06, SSE ± 315 Race: Caucasian = 0, Mohawk = 1 When the three-day mean AC was forced into the model, the amount of variation in AEE was explained, did not increase significantly R^2 = 0.29, P = .12, SSE = ±321
RT3 accelerometer (Stayhealthy, Monrovia, CA). The instrument measures the acceleration in three dimensions: anterior-posterior (x), medio-lateral (y), and vertical (z) directions. Activity counts is the square root of the sum of the squared accelerations of each direction.	Indoor: laying down, sitting relaxed, writing, standing relaxed, sitting and standing (alternating every 5 s), cycling, stepping up and down, walking. The speed of treadmill was predetermined so that most children could complete jogging on the treadmill. Outdoor: picking up tennis balls, and then standing up, catching and passing a basketball, kicking a soccer ball, shooting a basketball while walking, walking relaxed nonlinearity, jogging lightly, and jogging fast.	Indirect calorimetry	Sun et al. [18] The RT3 was placed at the waist/midline thigh. Indoor activities: AEE (kcal · min^{-1}) = 0.0006359 (counts · min^{-1}) −0.0006427 (body weight) + 0.733 (Activity counts is the square root of the sum of the squared accelerations of each direction) r=.95 (R^2 =.90), P = .001. B&A: mean error 0.94 kcal · min^{-1}, 95% confidence interval = (−1.83,2.77) kcal · min^{-1}. Outdoor activities: AEE (kcal · min^{-1}) = 0.00030397 (counts · min^{-1}) + 0.00586272 (body weight) + 0.58 r=.78 (R^2 =.61), P < .001. B&A: mean error −1.66 kcal · min^{-1}, 95% confidence interval (−3.2, 1.57) kcal · min^{-1}.

Abbreviations: AC: Accelerometer Counts, adj.: adjusted, AEE: Activity related Energy Expenditure, B&A: Bland & Altman, bpm: beats per minute, CI: Confidence Interval, FFM: Fat Free Mass, FM: Fat Mass, g: gram, h: hour, Hz: hertz, J: Joule, kcal: Kilocalorie, kg: kilogram, min: minute, r= correlation coefficient, RMSE: Root Mean Squared Error, SEE: Standard Error of the Estimate, SSE: Sum of Squared Errors.

Table 2: Items concerning study design.

1	*Sample characteristics (n, sex, age, weight, height, BMI% body fat/sum of skin folds, health status)*
1	≥6 sample characteristics are described (at least: *n*, sex, age, weight, and height)
0.5	4-5 sample characteristics are described
0	≤3 sample characteristics are described
2	*Protocol*
1	Information on setting, activities, duration (days or hours), and period of wearing the motion sensor
0.5	Information on period of wearing the motion sensor is missing
0	Not clear at all
3	*Measurements*
1	Complete information on motion sensor (type, output, epoch, placement) and reference method(s) (type, output)
0.5	Some information on motions sensor (type, output, epoch, placement) and reference method(s) (type, output) is missing
0	Very limited information on motion sensor (type, output, epoch, placement) and reference method(s) (type, output)
4	*Statistical analyses*
1	Complete information on statistical analysis (tests, subgroup analysis), statistical software package and *P*-value
0.5	Some information on statistical analyses (tests, subgroup analysis), statistical software package and *P*-value
0	Very limited information on statistical analysis (tests, subgroup analysis), statistical software package and *P*-value

error, Corder et al. [14] concluded that these models can be used to predict overall AEE on a group level, during the six activities used in this protocol.

The studies of Puyau et al. [10, 17] derived three models for the Actiwatch. One study compared estimations from the Actiwatch placed at the hip and at the leg (fibula head) [17]. In the other study the Actiwatch was only placed at the hip [10]. The range of explained variance in measured AEE was 71%–81%. Highest explained variance was obtained when the Actiwatch was placed at the hip. A combination of both locations raised the explained variance of measured AEE to 84%. Puyau et al. [17] regarded this as a marginally improvement, not worth the increased cost, time, and effort. Puyau et al.[17] found the regression of AEE on counts to be independent of age and sex, therefore the prediction model was based on Actiwatch counts alone. Given the large standard of the estimate (SEE 0.0147 $\text{kcal} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) the prediction model was inappropriate for individuals.

The study of Johnson et al. [16] aimed to derive a prediction model for the Caltrac during free-living. Since the Caltrac counts showed no significant correlation with measured AEE, a prediction model without counts was derived. This model explained 28% of the variance in measured AEE by doubly labelled water, and consisted of gender, race/ethnicity (Caucasian, Mohawk), fat mass and fat free mass. When the mean Caltrac counts were forced in the model the explained variation in measured AEE still was only 29% making it unacceptable as an estimate of AEE.

Two prediction models were derived by the study of Sun et al. [18] for the RT3 accelerometer, one concerning indoor activities, one concerning outdoor activities. The indoor model explained 90% of the variance in measured AEE, the outdoor model 61%. Both models contained counts and body weight. Sun et al. concluded that despite underestimation of AEE during sedentary activities and overestimation of AEE in moderate, and vigorous activities by the RT3, their results indicated that the RT3 accelerometer might be used to provide acceptable estimates of physical activity in children.

3.3. Generalizability. Corder et al. [14] analysed the generalizability of the prediction models from Puyau et al. [17] and Trost et al. [19]. Puyau's model was originally derived with various sedentary, light, moderate and vigorous activities. In the protocol of Corder et al. the Puyau model explained 84% of the variance in measured AEE (RMSE 245.3 $\text{J} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). Mean bias was -151.6 $\text{J} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, the limits of agreements were −160.4 to −142.8 $\text{J} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. The Trost model (85%) was the most accurate of the two with the lowest RMSE (126.0 $\text{J} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). Mean bias on ratio scale was 5.5, the limits of agreement were −3.6 to 14.6. In the study of Corder et al. [14] most of the accelerometer counts models overestimated AEE during sedentary activities, and all the accelerometer counts models underestimated AEE for high-intensity activities, to the greatest extent during jogging. This was a systematic error, an intensity or activity dependent error. This bias and large range of the 95% ratio limits of agreement suggested that the models are only accurate for the assessment of group-level AEE.

Trost et al. [11] analysed the same Puyau et al. [17] model for the ActiGraph/CSA hip in their study concerning over ground walking and running. An overall mean pure error of 0.049 $\text{kcal} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ was found. (The pure error is calculated as the square root of the sum of squared differences between the observed and predicted values divided by the number of observations. The smaller the pure error, the greater the accuracy of the equation when applied to an independent sample [11].)

Mean bias on ratio scale was 1.33 (a difference between measured and predicted AEE of +33%). The corresponding limits of agreement were 0.44–2.22. Thus for any individual in the population, AEE values predicted by the Puyau et al. [17] model may differ from measured AEE values by −56 to +122%. Based on these findings Trost et al. [11] concluded

Table 3: Items concerning validity.

5		*Is "criterion" validity reported for the prediction model?*
	1	Yes
	0	No
6		*Adequate measure of validity?*
	1	Sensitivity
	1	Specificity
	1	Pearson's product-moment correlation coefficient
	1	Spearman's rank order correlation coefficient
	0.5	95% limits of agreement (Bland and Altman)
	0	Other measure
7		*Acceptable level of criterion validity?*
	+	$r \geq 0.60$
	±	$r = 0.30–0.60$
	−	$r < 0.30$
8		*Is reliability reported for the prediction model? (cross validation analysis)*
	1	Yes
	0	No
9		*Adequate measure for reliability?*
	1	Intraclass correlation coefficients
	1	95% limits of agreement (Bland and Altman)
	1	Cohen's Kappa
	1	Standard error of measurement
	1	Coefficient of variation
	0	Pearson's product-moment correlation coefficient
	0	Spearman's rank order correlation coefficient
	0	Kendall's tau
	0	Other measure
10		*Acceptable level of reliability?*
	+	ICC ≥ 0.70
	±	ICC = 0.40 − −0.70
	−	ICC < 0.40

Table 4: Items concerning feasibility.

11		*Is the amount of missing/lost data due to (malfunctioning of) the motion sensor reported/reducible?*
	1	Yes
	0	No
12		*Acceptable amount of missing/ lost data?*
	+	≤5%
	−	>5%
13		*Is the refusal rate of, or the compliance rate with wearing the motion sensor reported?*
	1	Yes
	0	No
14		*Acceptable refusal rate?*
	+	<15%
	±	15–30%
	−	≥30%

that this prediction model does not accurately predict AEE during over ground walking and running. The model might be useful however for estimating participating in moderate and vigorous activity.

4. Discussion

This review shows that accelerometer-based prediction models can explain up to 91% [14] of the variance in measured AEE in children. Models derived in laboratory settings, using structured activities, provide estimations of AEE up to 91% [14], models derived free-living provide estimations of AEE up to 45% [15]. Laboratory-based models that explained ≥90% of the variance in measured AEE included heart rate [13, 14] or were based on the counts of a triaxial accelerometer (RT3) combined with body weight [18].

The difference found between laboratory-based models and free-living models might be explained by the derivation activities and the limitations of accelerometers. AEE predicted by a linear model, is likely to be more accurate when this model is derived and applied on a limited set of structured activities such as running and walking [20]. Activities free-living are much more complex and various then those included in a laboratory protocol. Moreover, the known limitations of accelerometers might cause deviations in the estimation of AEE free-living. Most accelerometers are mainly sensitive for accelerations in the vertical plane and less sensitive for more complex movements [13]. Accelerometers are limited in sensing activities as walking or cycling on a gradient. Also an increase in EE without a proportional increase in the amount of body movement is not detected (load-carrying, pushing and lifting objects) which causes estimation errors [13, 17].

Our findings suggest that the accuracy of the prediction model seems improved when a triaxial accelerometer is used. A triaxial accelerometer captures more movements than uniaxial and omnidirectional accelerometers. In the review of Westerterp [21] was concluded that the triaxial accelerometer can distinguish differences in activity levels in individuals. Especially sedentary activities were better reflected with a triaxial accelerometer than with an uniaxial accelerometer.

Models that included heart rate explained 86–90% of the variance in measured AEE [13, 14]. Due to the limitations of accelerometers there is no linear relation between the accelerometer counts and the measured AEE, adding heart rate in the prediction model may provide more accuracy [13, 14]. Corder et al. found a systematic error in all used prediction models which was intensity dependent. This systematic error was larger for the models without heart rate. The accelerometer counts models seemed more dependent on the activities tested (intensity), whereas the combined models (counts en heart rate) seemed more dependent on

Table 5: Data of included studies.

Study	Population	Score checklist (out of 10)	Setting	Accelerometer (placement)	Prediction model(s)	Conclusion authors
Corder et al. [13]	39 children aged 13.2 ± 0.3 yr, 23♂, 16♀.	7.5	Laboratory setting.	*Actiheart* (chest) *Actigraph* (hip, ankle) *Actical* (hip)	Six prediction models were derived, one not consisting of accelerometer counts, this one was excluded.	Corder et al. concluded that the combined HR and activity monitor Actiheart is valid for estimating AEE in children during treadmill walking and running. The combination of HR and activity counts provides the most accurate estimate of AEE as compared with accelerometry measures alone.
Corder et al. [14]	145 children aged 12.4 ± 0.2 yr, 66♂, 79♀.	7.5	Laboratory setting.	*Actigraph* (hip) *Actiheart* (chest)	Five previously published prediction models (Coder et al. [13](3), Puyau et al. [17], Trost et al. 19)Three derived using the current data.	Corder et al. concluded that the ACC and HR + ACC can both be used to predict overall AEE during these six activities in children; however, systematic error was present in all predictions. Although both ACC and HR + ACC provides accurate predictions of overall AEE, according to the activities in their study, Corder et al. concluded that AEE-prediction models using HR + ACC may be more accurate and widely applicable than those based on accelerometry alone.
Ekelund et al. [15]	26 children aged 9.1 ± 0, 3 yr, 15♂, 11♀.	8.0	Free-living.	*Actigraph/CSA* (centre of gravity/lower back)	One prediction model derived.	Ekelund et al. concluded that activity counts contributed significantly to the explained variation in TEE and was the best predictor of AEE. Their cross-validation study showed no significant differences between predicted and measured AEE. However the relatively large SEE together with the wide limits of agreement preclude individual comparison. Ekelund et al. suggested therefore that the prediction equation could be used to assess the mean AEE on a group level.
Heil et al. [9]	24 children: 14♂ aged 12 ± 3 yr, 10♀ aged 13 ± 2 yr.	5.5	Laboratory setting.	*Actical* (wrist, ankle, hip)	Nine prediction models derived.	Heil et al. concluded that the proposed algorithms for the Actical appeared to predict AEE accurately whether worn at the ankle, hip or wrist. Additionally they state that their results however, are clearly limited by the laboratory nature of the data collection and need to be validated under free-living conditions. In practice, according to Heil et al., may provide their algorithms useful predictions of AEE for groups of children, but the tracking of individuals may still involve considerable error.
Johnson et al. [16]	31 children aged 8.3 ± 2.0 yr, 17♂, 14♀.	5.0	Free-living.	*Caltrac* (hip)	Sallis et al. 1989 equation; originally validated against HR, thus excluded in this study. One prediction model derived.	According to Johnson et al. their study failed to find a significant correlation between either activity counts and AEE or Caltrac average calories with AEE. Their major finding was that the Caltrac accelerometer was not a useful predictor of AEE in the sample. Johnson et al. concluded that the equation consistently overestimated AEE and had wide limits of agreement, making it unacceptable as an estimate of energy expended in physical activity for this sample.

Table 5: Continued.

Puyau et al. [17]	26 children 14♂ aged 10.7 ± 2.9 yr, 12♀ aged 11.1 ± 2.9 yr.	5.5	Laboratory setting.	*Actigraph/CSA* *Actiwatch* (both: hip, fibula head)	Four prediction models were derived.	Puyau et al. concluded that the high correlations between the activity counts and AEE demonstrates that the CSA and Actiwatch monitors strongly reflected energy expended in activity. Given the large SEE of the regression of AEE on activity counts, they found the prediction of AEE from CSA of Actiwatch activity counts inappropriate for individuals.
Study	Population	Score checklist (out of 10)	Setting	Accelerometer (placement)	Prediction model(s)	Conclusion authors
Puyau et al. [10]	32 children aged 7–18 yr, 14♂, 18♀.	5.5	Laboratory setting.	*Actiwatch Actical* (both: hip)	Two models derived.	Puyau et al. concluded that activity counts accounted for the majority of the variability in AEE with small contributions of age, sex, weight, and height. Overall, Actiwatch equations accounted for 79% and Actical equations for 81% of the variability in AEE. Relatively wide 95% prediction intervals for AEE showed considerable variability around the mean for the individual observations. Puyau et al. suggest that accelerometers are best applied to groups rather than individuals. According to Puyau et al. provided both accelerometer-based activity monitors valid measures of children's AEE but require further development to accurately predict AEE of individuals.
Sun et al. [18]	27 children aged 12–14 yr, 21♂, 6♀ (25 indoor, 18 outdoor).	8.0	Laboratory setting.	*RT3* (waist/midline thigh)	Two models derived and manufacturer's model was used. Since the manufacturer's model is not revealed it was excluded.	Sun et al. concluded that the results of their study show that the RT3 accelerometer provides a valid method to examine physical activity patterns qualitatively and quantitatively for children. The moderate to high correlation coefficients between the physical activities in various lifestyle conditions from this device and the metabolic costs in simulated free-living conditions strongly supports, according to Sun et al., that the RT3 accelerometer serves as a valid, objective measure of physical activity of children, even in a tropical environment such as Singapore.
Trost et al. [11]	45 children aged 13.7 ± 2, 6 yr, 22♂, 23♀.	5.5	Laboratory setting.	*ActiGraph* (hip)	Validation of three models. Two models not concerning AEE were excluded. The model by Puyau et al. [17] was included.	Trost et al. concluded that previously published ActiGraph equations developed specifically for children and adolescents do not accurately predict AEE on a minute-by-minute basis during overground walking and running.

Abbreviations; ACC: Accelerometer, AEE: Activity related Energy Expenditure, HR: Heart Rate, SEE: Standard Error of the Estimate, TEE: Total Energy Expenditure, yr: year.

participant characteristics. The combined models may be more accurate and widely applicable [14].

The generalizability of the models is however limited and seems mainly dependent on the derivation activities. Nilsson et al. [20] compared several accelerometry prediction models in a large sample of children ($n = 1321$) during free-living in four different countries. The predicted AEE differ substantially between the models.

Free-living studies are most likely to represent actual daily activities performed by children. The laboratory-placed studies, included in this review, attempted to represent these activities by including locomotion activities [9–11, 13, 14, 17, 18], sports activities [10, 14, 17, 18], and recreational activities like playing video or computer games [9;10;17]. It remains however debatable whether treadmill walking [9, 10, 13, 17, 18] and cleaning activities [9, 10] actually represent the physical activity and the resulting AEE of activities daily performed by children. The chosen derivation activities will affect the linear relation between the accelerometer counts and AEE [20]. Nilsson et al. state that it is therefore unlikely that laboratory-based prediction models, using specific activities, are valid throughout the range of free-living activities [20].

Free-living studies estimate AEE by subtracting REE from total energy expenditure (TEE) provided by the doubly labelled water method [15, 16]. The included laboratory placed studies estimated AEE by subtracting REE from the EE provided by indirect calorimetry [9–11, 13, 14, 17, 18]. Seven of the included studies measured REE [9, 10, 13, 14, 16–18]. In two studies REE was predicted by the Schofield prediction equations [11, 15, 22]. The Schofield equations have good agreement with measured REE in healthy children and adolescents [23]. However, when indirect calorimetry is available, measurement of REE is preferred and more accurate, especially in children with chronic disease and movement disorders [24–26].

Measurement is more accurate since REE can vary with age, maturation, body mass, and level of physical activity [9]. Obviously a better estimation of AEE is obtained with a more accurate, measured REE.

Implication for clinicians is that previously published prediction models have limited applicability. Laboratory-based models can be used, on a group level, to predict AEE during specific activities, similar to the derivation activities. The use of a model combining accelerometer counts and heart rate, or a model combining triaxial accelerometer counts with body weight enhances validity. Generalizability of the models during free-living, however, is very limited. This is a significant limitation because measurement during free living is important to examine the dose-response relationship between physical activity and health-related fitness. The model derived by Ekelund et al. can be used, on a group level, for the prediction of AEE during free-living in 9-year-old children [15]. As stated before this model explained 45% of the variance in measured AEE.

Future development of prediction models applicable to free-living scenarios is needed. Future free-living studies should concern prediction models combining accelerometer counts and heart rate, or the counts of a triaxial accelerometer. As stated by Corder et al. especially the combination of accelerometer counts and heart rate might provide a more accurate and widely applicable model [14].

Regarding the reporting of findings, future recommendation is the description of the correlation between counts and measured AEE, since the counts are part of the prediction model. The limitations of the accelerometer itself may cause less accuracy, and therefore a less accurate prediction of AEE by the model.

To assess feasibility, authors should also report the amount missing and lost data due to malfunctioning of the motion sensor. Regarding free-living studies is additionally the refusal rate, or compliance rate with wearing the motion sensor interesting for clinicians.

5. Conclusion

Accelerometry based prediction models may provide an accurate estimate of AEE in children on a group level. The estimation of AEE is more accurate when the model is derived (and used) in a laboratory setting. The best results are retrieved when the model combines accelerometer counts with heart rate or when a triaxial accelerometer is used. Generalizability of the models during free-living however is limited. Future development of equations applicable during free-living is needed.

There are no professional relationships with companies or manufacturers who will benefit from the results of the present study.

Appendices

A. Checklist Methodological Issues

Evaluation checklist for studies on prediction models for accelerometers

Source; Clinimetric review of motion sensors in children and adolescents. Journal of Clinical Epidemiology 59 (2006) 670–680. De Vries SI, Bakker I, Hopman-Rock M, Hirasing RA, van Mechelen W.

Modified by S. de Graauw, 2009.

See Tables 2–4.

B. Data of Included Studies

See Table 5.

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