Hindawi Publishing Corporation
ISRN Stroke
Volume 2013, Article ID 464176, 13 pages
http://dx.doi.org/10.1155/2013/464176

Review Article

Physical Activity after Stroke: A Systematic Review and Meta-Analysis

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Received 17 June 2013; Accepted 7 July 2013

Academic Editors: H. McNaughton and C. Zweifel

Background and Purpose. Physical activity is beneficial after stroke, but it is unclear how active stroke survivors are. This systematic review and meta-analysis sought to determine levels of activity and factors predicting activity. *Summary of Review*: *Methods*. MEDLINE (1946 to present) and EMBASE (1980 to present) were systematically searched until July 2012. All studies quantifying whole-body-free living physical activity by objective and self-reported methods in a community dwelling population with stroke were included. A random effect meta-analysis was performed. *Results*. Twenty-six studies were included ($n = 1105$), of which eleven ($n = 315$) contained sufficient data for meta-analysis. There were heterogeneous designs, measurements, and procedures. The studies generally recruited small samples of high-functioning participants. Level of physical activity was generally low in quantity, duration and intensity. Poorer walking ability, specific sensorimotor functions, and low mood were correlates of low physical activity. Meta-analysis generated an estimate of 4355.2 steps/day (95% CI: 3210.4 to 5499.9) with no significant heterogeneity ($I^2 = 0$). *Conclusions*. In high-functioning stroke survivors, physical activity including walking was generally low. Strategies are needed to promote and maintain physical activity in stroke survivors. Research is needed to establish reasons for low physical activity after stroke.

1. Introduction

Physical activity is defined as "any bodily movement produced by skeletal muscle that results in energy expenditure above a basal level" [1] and is associated with improved cardiovascular risk factors including reduced blood pressure [2]. The risk of a first-ever stroke, ischaemic or haemorrhagic, is associated with lower amounts of physical activity [3, 4]. Risk modelling studies, based on data from primary prevention studies, have suggested that physical activity is likely to reduce the risk of recurrent stroke [5]. Thus, the American Heart Association (AHA) recommends 20–60 minutes medium to high intensity exercise (expressed as 40–70% of either peak oxygen uptake or heart rate reserve) in 3–7 days per week for stroke survivors [6].

Therefore, it is important to understand whether stroke survivors meet AHA recommendations for physical activity after stroke and the factors associated with the amount and intensity of physical activity patterns. The most methodologically robust way to synthesise results of observational studies is by systematic review and meta-analysis. To our knowledge, the amount of physical activity performed after stroke has only been reviewed in an inpatient setting [7]. The amount of free-living activity after discharge from hospital is likely to be important for secondary prevention of recurrent vascular events and long term health. A review of the amount of free-living physical activity performed by community dwelling stroke survivors is therefore required.

A systematic review and meta-analysis was performed to determine

(a) how much physical activity is performed in community dwelling stroke survivors?

(b) what factors are associated with the amount and intensity of physical activity performed?

2. Methods

2.1. Inclusion Criteria

2.1.1. Study Designs. We included any published papers/letters, in all languages, reporting data on whole-body free-living physical activity in 10 or more stroke survivors using data from cross-sectional and longitudinal studies and baseline data from Randomised Control Trials (RCTs). We excluded data published only in abstracts and doctoral dissertations.

2.1.2. Participants. We included studies recruiting community dwelling stroke survivors over 18 years of age.

2.1.3. Physical Activity Measures. We included papers quantifying whole-body free-living physical activity by any method, including (but not limited to) self-report (activity scales, activity diaries, questionnaires, and recall interviews) and movement sensors (e.g., accelerometers and pedometers). Studies reporting gait patterns, walking/activity capacity, ability to perform activities of daily living (e.g., Barthel's index and Nottingham Extended Activities of Daily Living) which did not qualify amount of physical activity were excluded. We excluded studies reporting upper limb activity and not whole-body activity, as upper limb activity is nonweight bearing, requires lower metabolic output/energy expenditure than whole-body activity [8], and is therefore less likely to achieve moderate intensity as defined by the AHA.

2.2. Search Strategy. We searched Ovid MEDLINE (In-Process and other Non-Indexed citations and MEDLINE (R) 1946 to Present) and Ovid EMBASE (1980 to present) (July 4th 2012). Two key search terms, stroke, physical activity, and their synonyms were combined using MeSH headings and key word searches (further information available on request). We scrutinised reference lists of all systematic and other relevant reviews.

2.3. Study Selection. One review author (MF) eliminated duplicate and obviously irrelevant studies based on the title and abstract. Full texts of the remaining papers were obtained. Two review authors (MF, GM) independently scrutinised full texts and applied inclusion criteria. Any disagreements were resolved through discussion.

2.4. Data Extraction and Analysis. Two authors (MF and either TS, NG, or SN) independently extracted data (study design, source population, participants, outcome measures, results) into a previously piloted extraction form.

2.4.1. Quality Assessment. We used the Downs and Black checklist [9], to assess methodological quality, omitting items relating to interventions and adapting questions to make them appropriate for all study designs (further information available on request).

Discrepancies in quality assessment and data extraction were resolved through consensus discussion.

2.4.2. Data Analysis. We narratively reviewed data. We produced a Forest plot of step counts per day (in Microsoft Excel), for studies that reported mean (SD) step counts [10]. We meta-analysed the data using a random effects model. For studies reporting step count at two separate time points, we used the highest count. For baseline data from RCTs, we included both the experimental and control group.

3. Results

After removal of duplicates, there were 32,363 citations, from which 116 full texts were identified as potentially eligible (Figure 1). All but one full text could be retrieved. A further 9 full texts were obtained following scrutiny of reference lists. 124 full texts were reviewed based on the criteria of quantifying whole-body free-living physical activity of which 36 papers reporting on 26 separate studies fulfilled the specified inclusion criteria [11–46].

3.1. Characteristics of Included Studies. The 26 studies recruited 1105 stroke survivors from 14 countries from a wide range of sources. Two studies did not report source of participants [44, 45]. Fourteen studies used a convenience/volunteer sample, two used an unselected or random sample, two used subsets from larger trials, and eight did not report recruitment methods. Eighteen studies were cross-sectional [13, 15, 18–22, 25, 27, 31, 32, 36–38, 40, 42, 44, 46], six of which included activity from healthy controls [13, 20, 22, 25, 40, 46]. Two studies were longitudinal [24, 39] and six were baseline data from clinical trials [16, 30, 34, 41, 43, 45]. Scores for study quality ranged from 7 to 18 out of a maximum of twenty.

Mean age ranged from 52.8 yrs to 72.6 yrs. Mean time since stroke ranged from 3 months to 8.5 years. All but four studies [15, 39, 40, 45] recruited ambulatory participants. Of the studies recruiting ambulatory participants, thirteen required participants to walk without assistance from another person [13, 16, 18–20, 22, 30–32, 34, 38, 41, 43], two allowed personal assistance [21, 29], and two required participants to be mobile at home or in the community [42, 46]. Eight studies also required a specific gait deficit [19, 21, 29–32, 43, 44]. Studies generally excluded stroke survivors with comorbidities.

Twenty-one studies ($n = 660$) used at least one objective measure of physical activity (Table 1) including pedometers [15, 38, 43, 44] and accelerometers [13, 19–22, 24, 25, 27, 30–32, 36, 37, 39, 42, 45, 46]. Six of these also used self-reported methods [15, 22, 30, 35, 37, 46] and one also used participant observation [11]. Five studies ($n = 445$) used self-reported questionnaires only [16, 18, 34, 40, 41]. In total, eight different self-reported questionnaires were used.

Table 1: Characteristics and results of studies using objective measures of physical activity.

Reference	Design	Participants		Time since stroke	Measure of physical activity	Level of physical activity	Study quality max. = 20
		Sex (M = male; F = female)	Age (yr)				
Alzahrani et al. [11–14]	Cross-sectional	Stroke: M = 29; F = 13. Control: M = 11; F = 10.	Stroke: Mean = 70 (SD = 10) Control: Mean = 69 (SD = 7)	Mean = 2.8 yrs (SD = 1.4)	Intelligent device for energy expenditure and activity (five accelerometers) Duration: two separate randomly allocated days, not nights.	Adjustment to 12 hr observation period: Mean time on feet (mins) strokes = 256 (SD = 128) versus controls = 292 (SD = 97) [difference = −36 (95% CI −99 to −27)]. Mean activity counts: strokes = 6284 (SD = 4546) versus controls = 10346 (SD = 3590) [difference = −4062 (95% CI −6337 to −1787)].	15
Baert et al. [15]	Cross-sectional	M = 12; F = 4.	Mean = 61.9 (SD = 11.9)	1 year	Yamax SW-200 pedometer AND Polar RS-400 HR monitor, activity diary. Duration: 5 consecutive weekdays, not nights. Self-reported BPAQ* Self-reported PASIPD† (physical activity in previous 7 days).	Mean (SD, range): Heart rate monitor: (n = 12) Minutes/day of light activity = 149 (107, 37–368); Minutes/day of moderate activity = 44 (39, 0–132); Pedometer (n = 16): steps/day 6428 (4117, 1456–15604); BPAQ (sport index, range 1–5) 2.2 (0.7, 1.3–3.5); BPAQ leisure index 2.2 (0.6, 1.3–3.3); PASIPD (Mets hour/day range 0–199.5) 7.8 (7.6, 0.3–27.0)	14
Dobkin et al. [19]	Cross-sectional (Validity/reliability study)	M = 8; F = 4.	Mean = 58.9; range = 36–73	Mean = 27.25 months (median = 14.5 months, IQR = 3.5–31.5, range = 2–112 months)	Wireless triaxial accelerometer; Log of mobility activity; Duration: 24 hrs, not nights.	Steps per day: mean = 3759.9 (median = 3096.5, IQR = 2025.5–4475.25, range = 383–12082); hours monitored: mean = 8.75 (median = 8.375, IQR = 7.5–10.75, range = 4.75–13.25).	11
Fulk et al. [20]	Cross-sectional	Stroke = 19. Control = 13 (not stratified by sex)	Stroke: mean = 65.7 (SD = 11.9) Control: mean = 65.3 (SD = 8.5)	Mean = 42.1 months (SD = 36.1)	SAM‡ accelerometer; Duration: 1 week; not nights.	Mean steps per day: all stroke survivors = 3838.25 (SD = 1963.6) versus healthy control = 6294.0 (SD = 1768.0) [significantly fewer steps $P < 0.05$].	12
Haeuber et al. [21]	Cross-sectional	Total = 17 (not stratified by sex)	Mean = 65 (SD = 6)	Mean = 41.6 months (range = 9–120 months)	SAM‡ accelerometer; Caltrac accelerometer (total caloric expenditure) Duration: two separate 48 hour periods within 3 weeks; including nights.	Mean steps per day: test period 1 = 3049 (SD = 1918); test period two = 3021 (SD = 2042); total mean = 3035 (SD = 1944, range 336–6472). Caloric expenditure (Kcal/day): test period 1 = 294 (SD = 154); test Period 2 = 347 (SD = 279); total mean = 321 (SD = 187, range = 83–1222)	13

Table 1: Continued.

Reference	Design	Participants		Time since stroke	Measure of physical activity	Level of physical activity	Study quality max. = 20
		Sex (M = male; F = female)	Age (yr)				
Hale et al. [22]	Cross-sectional	Stroke: M = 10; F = 10. Controls: M = 1, F = 8.	Stroke: mean = 72 (SD = 7.1, range = 57–86); control: mean = 51 (SD = 18.1, range = 28–76)	Not reported (at least >6 months).	TriTrac RT3 triaxial accelerometer; Daily activity log, 7-day recall questionnaire. Duration: 7 consecutive days (Test 1) (repeated 8 weeks later (Test 2)); not nights.	Mean vector magnitude (MVM) in activity counts (AU) (7 days): [stroke: test 1 = 673,920 (SD = 379,495); test 2 = 573,403 (SD = 266,993)][controls: test 1 = 1,385,760 (SD = 719,868); test 2 = 1,490,363 (SD = 510,675)]. 7-day Recall Q (Kcal in seven days): [stroke: test 1 = 3645 (SD = 572); Test 2 = 2633 (SD = 607)] [controls: test 1 = 2413 (SD = 354); Test 2 = 2363 (SD = 327)].	16
Manns and Baldwin [24]	Longitudinal	M = 6; F = 4.	Mean = 66.3 (SD = 15.0)	Mean time from stroke to discharge (days) = 74.7 (SD = 31.1)	SAM‡ accelerometer. Duration: 2 days; not nights; repeated predischarge (T1) and for 3 days at two weeks post discharge (T2) and again at six weeks post discharge (T3).	Steps per day (mean (SD)): T1 = 5541.4 (1845.8); T2 = 5506.2 (2196.6); T3 = 6195.0 (2068.0) [no significant difference between T1 and T3]. Absolute activity (mins/day) (mean (SD)): T1 = 182.6 (38.5); T2 = 198.5 (69.0); T3 = 228.8 (65.4) [significantly more minutes of activity in T3 compared to T1 (P = 0.030)]. Intensity of activity (proportion of strides at <15, ≥15 to <40, ≥40 strides/minute) (%): low: T1 = 62.6 (8.6) T2 = 68.0 (12.5) T3 = 68.5 (8.4); moderate: T1 = 31.2 (7.4); T2 = 24.7 (7.3); T3 = 26.2 (5.4). High: T1 = 6.2 (5.0); T2 = 7.3 (10.7); T3 = 5.4 (5.8) [Intensity of activity did not vary significantly between T3 and T1].	12
Manns et al. [25, 26]	Cross-sectional	M = 4; F = 6. (and 10 matched controls)	Stroke: mean = 54.3 (SD = 3) controls: Mean = 54 (SD = 3)	7.5 (SD = 8.3, median = 4.2)	SAM‡ accelerometer. Duration: 4 days, not nights.	Steps per day (mean (SD)): strokes = 7379 (SD = 3107) versus controls = 14730 (SD = 4522) [significantly lower in strokes (P < 0.001)].	14
Michael et al. [27–29]	Cross-sectional	M = 42; F = 37.	Mean = 65 (range = 45–84)	Mean = 10.3 months (range = 6–166 months)	SAM‡ accelerometer, log of activities. Duration: 48 hrs, not nights.	Mean steps per day: Total steps = 1,389 (SD = 798, range = 256–4,476); Number of steps at low intensity	15

Table 1: Continued.

Reference	Design	Participants: Sex (M = male; F = female)	Participants: Age (yr)	Time since stroke	Measure of physical activity	Level of physical activity	Study quality max. = 20
						(<16 steps/minute) = 624 (SD = 289, range 120–1,545); medium intensity (≥16 and <30 steps/minute) = 640 (SD = 536, range = 12–3,217); high intensity (≥30 steps/minute) = 83 (SD = 168, range = 0–846).	
Mudge et al. [30]	Randomised Controlled Trial	Control: M = 13; F = 14. Experimental: M = 19; F = 12.	Control: median = 71.0 (range = 44.0–86.0) experimental: median = 76.0 (range = 39.0–89.0)	Control: median = 5.8 yrs (range = 0.5–18.7); experimental: median = 3.33 yrs (range = 0.6–13.3)	SAM‡ accelerometer; Duration: 3 consecutive days, not nights. Self-reported PADS§ score.	Baseline activity: Mean steps per day: control = 4616 (SD = 2618) versus experimental = 6679 (SD = 3792) (significantly different $P = 0.021$). Peak activity index (steps/min): control = 52.0 (SD = 15.9) versus experimental = 66.6 (SD = 23.3) (significantly different $P = 0.008$); Percentage time inactive (%): control = 84.1 (SD = 7.0) versus experimental = 81.6 (SD = 8.3) (not significantly different, $P = 0.235$); PADS: control = 63.6 (SD = 77.0) versus experimental = 75.2 (SD = 57.5) (not significantly different, $P = 0.516$).	17
Mudge and Stott [31]	Cross-sectional	M = 29; F = 20.	Mean = 67.4 (SD = 12.5, range = 38–89)	Mean = 66 months (SD = 61, range = 6–219)	SAM‡ accelerometer; Duration: 3 consecutive days; not nights.	Steps per day: median = 4765 (range = 1225–21,273); Percentage of time with no steps: median = 83% (range 53–96); number of steps at: low rate (<30 steps/min): mean = 2334 (SD = 565, range = 493–5331); high rate (>60 steps/min): median = 655 (range = 0–10,590); Peak activity index (Steps/min): mean = 58.7 (SD = 10.6, range = 17–112).	15
Mudge and Stott [32]	Cross-sectional	M = 23; F = 17.	Mean = 69.2 (SD = 12.6)	Mean = 5.1 yrs (SD = 5.1)	SAM‡ accelerometer; Duration: 3 consecutive days; not nights.	Total step count: mean = 6247 (SD = 4439); No. steps at high rate (>60 steps/min): mean = 1614 (SD = 2252); no. steps at low rate (<30 steps/min): mean = 2338 (SD = 1051); Peak activity index: mean = 58 (SD = 22).	13

Table 1: Continued.

Reference	Design	Participants		Time since stroke	Measure of physical activity	Level of physical activity	Study quality max. = 20
		Sex (M = male; F = female)	Age (yr)				
Rand et al. [35, 36]	Cross-sectional	M = 13; F = 27.	Mean = 66.5 (SD = 9.6, range = 49–82)	Mean = 2.9 (SD = 2.4)	Actical triaxial accelerometer; Duration: 3 consecutive days; not nights. Self-reported PASIPD† (max 199.5 MET h/d) (physical activity in preceding seven days);	Mean activity counts per day: paretic Hip = 55,886 (SD = 5696); nonparetic Hip = 53,075 (SD = 83,476); mean energy expenditure per day (Kcal/day): paretic hip = 163.1 (SD = 149.4); nonparetic hip = 155.9 (SD = 140.7); average time wearing accelerometer = 15 hrs/day (SD = 1.8, range = 10–18); inactive hours awake = 13 hrs/day (SD = 2); PASIPD (MET hr/day, 0–199.5): median = 10.3 (IQR = 6.1–17.1).	15
Resnick et al. [37]	Cross-sectional	M = 51; F = 36.	Mean = 63.7 (SD = 12.3)	Not reported (at least >6 months).	SAM‡ accelerometer; Duration of measurement: 48 hrs; including nights. Self-reported YPAS®: (total activity time and Kcal expended in a week)	Steps per 48 hrs: mean = 4055 (SD = 2401.2, range = 66–13,429); YPAS: minutes of activity per week: mean = 3021.84 (SD = 2539.92, range = 0.00–9967.50); minutes of moderate activity (exercise): mean = 753.94 (SD = 950.72, range = 0.00–5670.00).	10
Robinson et al. [38]	Cross-sectional	M = 27; F = 23.	Mean = 65.0 (SD = 8.4, median = 65.0 range = 50–79)	Mean = 85.0 months (SD = 89.9, median = 34.5, range = 6–358)	VKR fitness twin step pedometer. Duration of measurement: 7 days, excluding nights.	Steps per day (pedometer (n = 44)): mean = 2,540 (SD = 2176); median = 2,140 (range 0–10,754).	15
Shaughnessy et al. [39]	Longitudinal	M = 10; F = 11.	Mean = 68 (SD = 12.8, range = 48–91)	Not reported	SAM‡ accelerometer; Duration: not reported	Mean daily steps (SAM) (n = 19): Time 1 (baseline): 1536 (SD = 106); Time 2 (3 months later): 2765 (SD = 1677) (significant increase from baseline (80%) at 3 months ($P < 0.001$)).	12
Van Den Berg-Emons et al. [42]	Cross-sectional	M = 20; F = 18.	Mean = 57 yrs (SD = 13)	Not reported	Four uniaxial piezoresistive accelerometers (on wrists if depended on wheelchair) Duration: 24 hrs, including nights.	Duration physical activities (% of 24 hrs) = 6.8 (SD = 4.5); % subnormal (average duration of physical activities in stroke survivors divided by average duration in able-bodied age-mates × 100) = 61% (significantly lower than able bodied subjects ($P \leq 0.01$)).	11
van Swigchem et al. [43]	Prospective cohort nonrandomised, noncontrolled trial	M = 19; F = 5.	Mean = 52.8 (range = 21–68)	Mean = 38 months (range = 7–105)	Pedometer (Yamax Digiwalker SW-650) Duration: 7 days; nights unknown.	Mean steps per day: AFO = 5541 (SD = 2900); FES = 5733 (SD = 2516) (no significant difference between the two scores (P = 0.548)).	14

Table 1: Continued.

Reference	Design	Participants		Time since stroke	Measure of physical activity	Level of physical activity	Study quality max. = 20
		Sex (M = male; F = female)	Age (yr)				
Viosca et al. [44]	Cross-sectional validation	M = 20; F = 11.	Mean = 64 (SD = 7.8)	Not reported	Two pedometers Duration: 48 hrs, not nights.	Mean number of steps per 48 hrs categorised by functional ambulation classification (Level 0 = absolute walking incapacity; Level 3 = patients walk indoors, outdoors and climb occasional stair; Level 5 = normal): Level 0 = 8; Level 1 = 395; Level 2 = 2728; Level 3 = 10,503; Level 4 = 11,572; Level 5 = 19,169.	13
Yoneyama et al. [45]	Randomised Controlled Trial	Not reported; Indeloxazine group = 12; Ticlopidine group = 5.	Indeloxazine: mean = 71.2 (SD = 7.4); Ticlopidine: mean = 72.6 (SD = 10.4)	Range = 1–3 months	Actigraph triaxial accelerometer Duration: 24 hrs; including nights.	Movements per 24 hr at baseline for each treatment group: Indeloxazine group: Mean = 74,438 (SD = 22,697); Ticlopidine group: Mean = 86,222 (SD = 17,433).	7
Zalewski and Dvorak [46]	Cross-sectional	Stroke: M = 14; F = 3. Control: M = 3; F = 16.	Stroke: mean = 71.3 (SD = 9.5); control: mean = 68.1 (SD = 7.0).	Not reported; mean time since discharge from rehabilitation = 2.2 yrs (range = 8 months to 7.2 years)	SAM[‡] accelerometer; Duration: 3 days (taking full 24 hrs of day 2 to calculate activity scores); including nights. Self-reported 7-day PAR[#] (measures energy expenditure).	Steps per day: stroke: mean = 2,990 (SD = 2,488); control: 6,378 (SD = 2,149) (significantly different (t test, $P < 0.05$)); Energy expenditure (unclear units) (7-day PAR): stroke: mean = 19,177 (SD = 6,457); control: mean = 19,918 (SD = 4,744) (not significantly different).	12

[*]Baecke Physical Activity Questionnaire; [†]Physical Activity Scale for Individuals with Physical Disabilities; [‡]StepWatch Activity Monitor; [§]Physical Activity and Disability Scale; [⊗]Yale Physical Activity Survey; [#]7-day Physical Activity Recall Questionnaire.

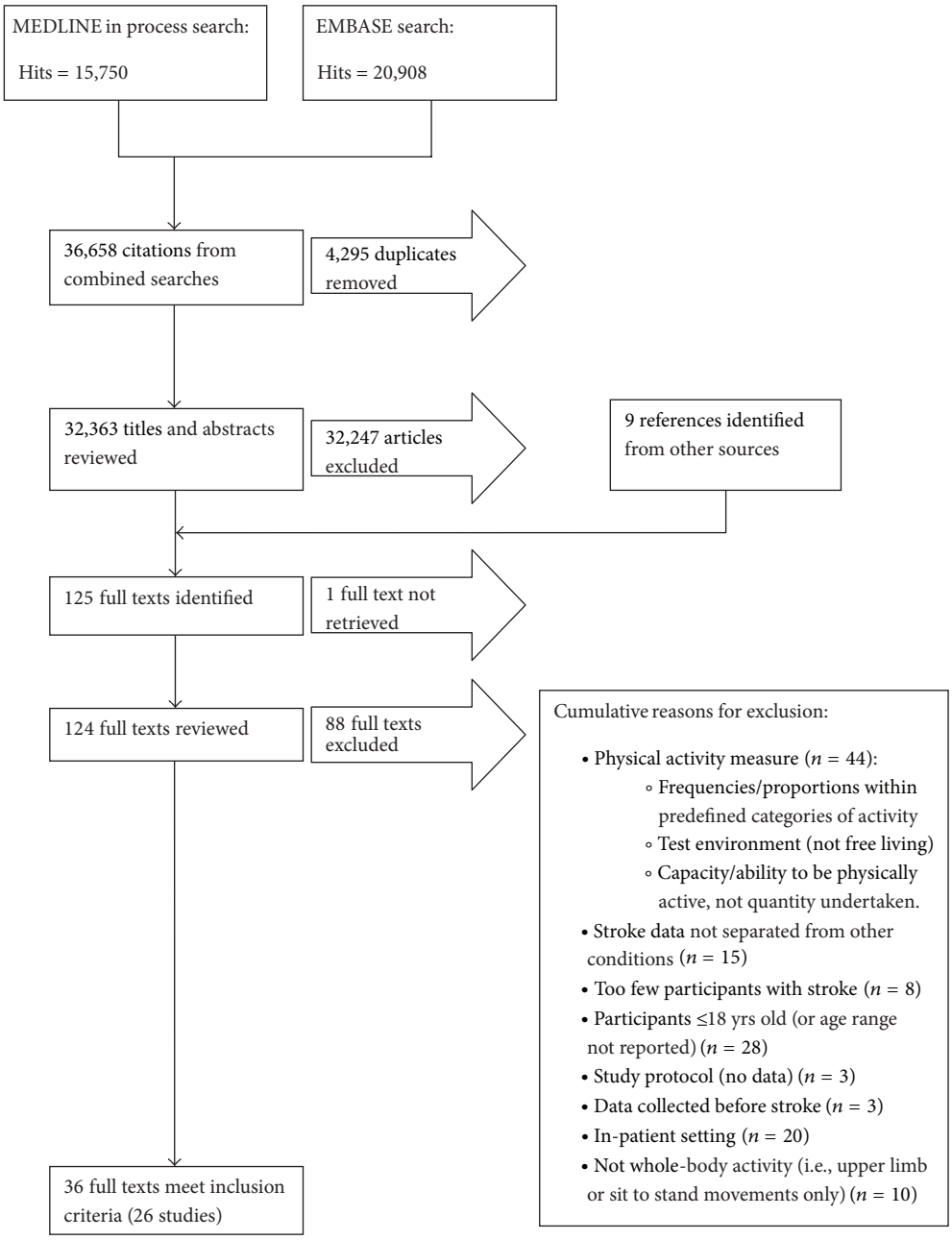

Figure 1: Flow diagram of selection process.

3.2. Physical Activity Level after Stroke

3.2.1. Steps and Activity Counts. Sixteen studies reported "step counts" for 17 different groups of stroke survivors [15, 19–21, 24, 25, 27, 30–32, 37–39, 43, 44, 46]. Mean number of steps per day ranged from 1,389 [27] ($n = 79$) to 7,379 [25]. All three of these sixteen studies which compared activity levels with healthy controls found that mean steps per day were significantly lower among stroke survivors [20, 25, 46]. A further two of these sixteen studies found an increase in mean daily steps at later followup compared with baseline [24, 39].

Eleven of these 16 studies, reporting mean daily step counts (eight using StepWatch Activity Monitors (SAM), three using pedometers) in 12 different groups of stroke survivors ($n = 315$), were eligible for inclusion in the meta-analysis [15, 20, 21, 24, 25, 27, 30, 38, 39, 43, 46]. The random effect summary was 4355.2 steps per day (95% CI: 3210.4 to 5499.9) with no significant heterogeneity ($Q = 10.25$, $I^2 = 0$) (Figure 2).

Four studies reported "activity counts" (raw data reflecting the number of movements detected by the accelerometer) instead of "step counts" [12, 22, 36, 45]. Per day, these ranged from 6,284 [12] to 86,222 [45].

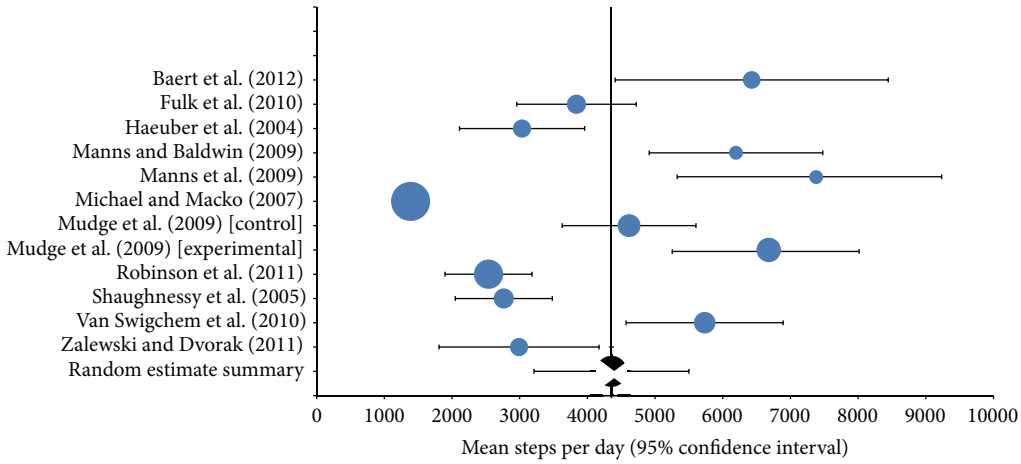

Figure 2: Forest Plot, mean steps per day.

3.2.2. Energy Expenditure. Four studies estimated energy expenditure [21, 22, 35, 46]. Of these, two studies used accelerometers reporting mean activity energy expenditure as 321 Kcal/day [21] and 155.9 Kcal/day [35]. Two studies used questionnaires reporting mean activity expenditure between 2633–3645 Kcal (excluding basal metabolic rate) [22] and 19,177 Kcal (including basal metabolic rate) over seven days [46].

3.2.3. Self-Reported Scale. Five studies (n = 445) used only a self-reported measure (see Table 2) [16, 18, 34, 40, 41]. Two of these used the Physical Activity Score for the Elderly (PASE) [16, 18], two used the Human Activity Profile [40, 41], and one used the Physical Activity Scale for Individuals with Physical Disability (PASIPD) measured in metabolic equivalents (MET hr/day) [34]. The two studies using the Human Activity Profile found lower mean adjusted activity scores among stroke survivors than healthy controls [40, 41].

3.2.4. Activity Duration and Intensity. Seven studies reported duration of activity over a variety of recording periods [12, 24, 30, 31, 36, 37, 42]. Four of these studies found that stroke survivors were active for less than 20% of the recording periods even when excluding sleep [30, 31, 36, 42]. Two studies found that stroke survivors were active for less than 40% of a 12 hour day [12, 24]. Resnick et al., using the Yale Physical Activity Scale, found that stroke survivors spent 30% of a week (including sleep) in activity [37].

Six studies measured intensity of activity by using a heart rate monitor [15] or calculating steps per minute [24, 27, 30–32]. All six studies found that a higher proportion of activity undertaken by stroke survivors was of lower intensity compared to higher intensity activity [15, 24, 27, 30–32]. Three calculated a peak activity index (mean steps per minute of the 30 most intensive individual minutes recorded) ranging from 52 to 66.6 steps/minute [30–32].

3.3. Correlates of Physical Activity. Seventeen studies investigated 56 potential correlates of physical activity [13, 15, 18, 20, 21, 23, 25, 29, 31, 33, 36–40, 44, 46]. Greater walking ability (as measured by functional ambulation level, 6 minute and 2 minute walk tests, walking speed, and ability to climb stairs) and better balance (as measured by Berg Balance Scale, 8 foot up and go test and single leg stance test) were generally associated with higher physical activity levels. Low mood was always found to be associated with lower physical activity levels. Higher cardiorespiratory fitness levels (as measured by VO_2 peak) were generally associated with higher physical activity levels. Age and other demographic variables including comorbidities did not tend to be associated with physical activity following stroke (data available on request).

4. Discussion

This is the first systematic review and meta-analysis to our knowledge to report the amount of "whole-body" physical activity in free-living stroke survivors. We were able to perform a meta-analysis of the studies reporting step counts; our summary estimate was only 4355.2 steps per day. This is well below steps per day in a healthy elderly population (6000 steps/day [47]) and even further below the recommended steps per day for people with chronic illness/disability (6500–8500 steps/day [48]).

Duration and intensity of physical activity were generally low. At least 3000 steps should be taken at a step rate of ≥100 steps/minute to meet international recommendations of 30 minutes per day of moderate intensity exercise [48]. Three studies found that average steps per minute of the most intensive 30 minutes (i.e., the 30 individual minutes containing the most steps) was considerably below this target [30–32]. Only one study (n = 16) measuring intensity by heart rate monitor combined with activity duration allowed comparisons to be made with AHA recommended physical activity levels [15]. With a mean of 44 minutes/day of activity at ≥40% heart rate reserve, its participants may have met the guidelines of 20–60 minutes of activity at 40–70% of heart reserve for 3–7 days per week [6, 15]. However, this finding cannot be generalised, especially considering

Table 2: Characteristics and results of studies using only self-reported measures of physical activity.

Reference and setting	Design	Participants		Time since stroke	Measure of physical activity	Level of physical activity	Study quality (out of 20)
		Sex (M = male; F = female)	Age (yr)				
Boysen et al. [16] and Lindahl et al. [23]	Multicentre, multinational, randomised clinical trial	Intervention: M = 89; F = 68. Controls: M = 88; F = 69.	Intervention: median = 69.7; IQR = (60.0–77.7) Control: median = 69.4; IQR = (59.6–75.8)	<90 days of stroke symptoms + follow up at 3, 6, 9, 12, 18, 24 months	Self-reported PASE* (range 0–400) (physical activity in preceding seven days) Collected in the week prior to stroke and at each followup time	Median PASE scores range between 3–24 months (control group: 64–68)	18
Danielsson et al. [17, 18]	Cross-sectional	M = 22; F = 9.	Mean = 59.7 (SD = 8.1, range = 36–73)	Mean = 8.5 yrs (SD = 0.9)	Self-reported PASE* (physical activity in preceding seven days)	Mean PASE score = 124 (SD = 67, range = 31–241)	15
Pang et al. [33, 34]	Randomised Controlled Trial	Intervention: M = 19; F = 13. Controls: M = 18; F = 13.	Intervention: mean = 65.8 (SD = 9.1); Control: mean = 64.7 (SD = 8.4)	Intervention: mean = 5.2 (SD = 5.0); Control: mean = 5.1 (SD = 3.6)	Self-reported PASIPD† (max. score 199.5 MET h/d) (physical activity in preceding seven days)	Baseline Physical Activity Level (MET h/d out of 199.5): intervention: mean = 7.9 (SD = 7.8); control: mean = 10.6 (SD = 9.8) (there was no significant difference between intervention and controls)	14
Teixeira-Salmela et al. [40]	Cross-sectional	Stroke: M = 13; F = 11. Control: M = 8; F = 15.	Stroke: mean = 63.69 (SD = 11.57, range = 39–84.5). Control: mean = 65.52 (SD = 6.35, range = 39–85)	2.03 yrs (SD = 2.41, range = 4 months to 8 years)	Self-reported HAP‡ (adjusted score measures average typical metabolic equivalent levels (MET) in a day based on energy expended in a variety of activities)	Stroke survivors adjusted HAP score: self-reported: mean = 52.79 (SD = 16.18, range = 25–84) observed: mean = 52.79 (SD = 16.12, range = 25–83) proxy: mean = 47.96 (SD = 18.69, range = 17–88)	15
Teixeira-Salmela et al. [41]	Randomised pretest posttest control group design	Total: M = 7; F = 6	Total: mean = 67.73 (SD = 9.2)	Total: mean = 7.67 yrs (SD = 9.42, range = 1–34)	Self-reported HAP‡ (see above)	Baseline adjusted HAP score: mean = 52.31 (SD = 13.28)	14

*Physical Activity Scale for the Elderly; †Physical Activity Scale for Individuals with Physical Disabilities; ‡Human Activity Profile.

the small sample ($n = 16$) in this study and the low intensity and duration of activity found in other studies. Activity levels may not always remain low; two studies with very small sample sizes reported that physical activity may increase over weeks and months after the initial stroke [24, 39].

Low physical activity is associated with reduced mobility, walking ability (6 minute walk test), aerobic fitness (VO_2 peak), reduced balance, and depression but not with age or other demographic variables. Establishing direction of causality in these associations is impossible with the available cross-sectional data; stroke impairments may directly lead to reduced activity levels, and reduced activity may lead to further reductions in fitness levels and thus mobility [6]. Similarly, low mood could be both cause and consequence of low physical activity, and depression/low mood could negatively affect self-efficacy, motivation, and self-determination which determine the uptake and maintenance of physical activity after stroke [49].

The strengths of this review include a very sensitive search strategy, thorough scrutiny of the reference lists, independent application of inclusion/exclusion criteria and data extraction by two authors, and a systematic quality assessment. A random rather than fixed effect meta-analysis ensured a more conservative summary estimate. Reporting all significant and nonsignificant results relating to physical activity reduced reporting bias. However, we searched only two databases and could not obtain one full text. Publication bias may have occurred for example, studies that did not demonstrate a difference between stroke survivors and healthy controls may not have been published. Furthermore, we excluded upper-limb studies because upper limb activity requires fewer metabolic equivalents than whole-body activity [8] and is therefore less likely to reach moderate intensity required to fulfil AHA recommendations.

The included studies had several limitations. Most did not report sample size calculations. Selection bias is likely because more physically active people may have agreed to participate. Most studies excluded more physically disabled stroke survivors and those with comorbidities. Thus, our summary estimate may overestimate activity levels, even among ambulatory participants. Moreover, the lack of longitudinal studies prevented the assessment of changing activity levels over time among stroke survivors.

Heterogeneity between studies in physical activity measures, numbers and duration of measurements, requirements to wear measuring devices at night and abnormal gait mechanics in hemiparetic participants may explain some variation in results. These differences also make drawing comparisons between the results challenging, especially between self-reported and objective measures. Accelerometers such as StepWatch Activity Monitor often show excellent validity and reliability in hemiparetic subjects [21, 50]. However, not all accelerometers demonstrate this [22, 51]. Furthermore, pedometers and self-reported measures are less valid and reliable than accelerometers [40, 50, 52, 53]. Accelerometers and pedometers could motivate the participant to do more activity than usual.

There are gaps in the current research. The relationship between time since stroke, BMI, social support, socioeconomic position, comorbidities, and physical activity were rarely investigated. Furthermore, most studies using objective methods of reporting physical activity (i.e., accelerometers and pedometers) reported activity in steps or counts which will mainly reflect activities such as walking and running. Activities such as swimming and cycling, therefore, may be underreported except in those studies which used self-reported measures. Moreover, the available cross-sectional data generally did not report prestroke variables, including prestroke physical activity.

Future studies should recruit larger, less highly selected samples of stroke survivors and should include activities other than just walking, to provide more accurate estimates of activity, and to enable multivariate analyses of the factors associated with physical activity after stroke. Studies measuring quantity, duration, and intensity with heart rate monitoring are required to assess all types of activity levels against AHA guidelines. Longitudinal studies are needed to determine whether activity increases over time.

In summary, stroke survivors do not reach recommended levels of activity, even those who are ambulatory. Further research is needed to identify how to promote physical activity amongst ambulatory stroke survivors, and how to reduce disability so that stroke survivors are able to participate in levels of physical activity that are likely to have an effect on secondary stroke prevention.

Conflict of Interests

The authors declare that they have no conflict of interests.

Acknowledgments

Sheila Fisken (University of Edinburgh Medical Librarian) and Alison McCulloch (previous medical student, University of Edinburgh) assisted with the development of the search strategy. Christine Chiong (medical student, University of Edinburgh) translated the Chinese papers.

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