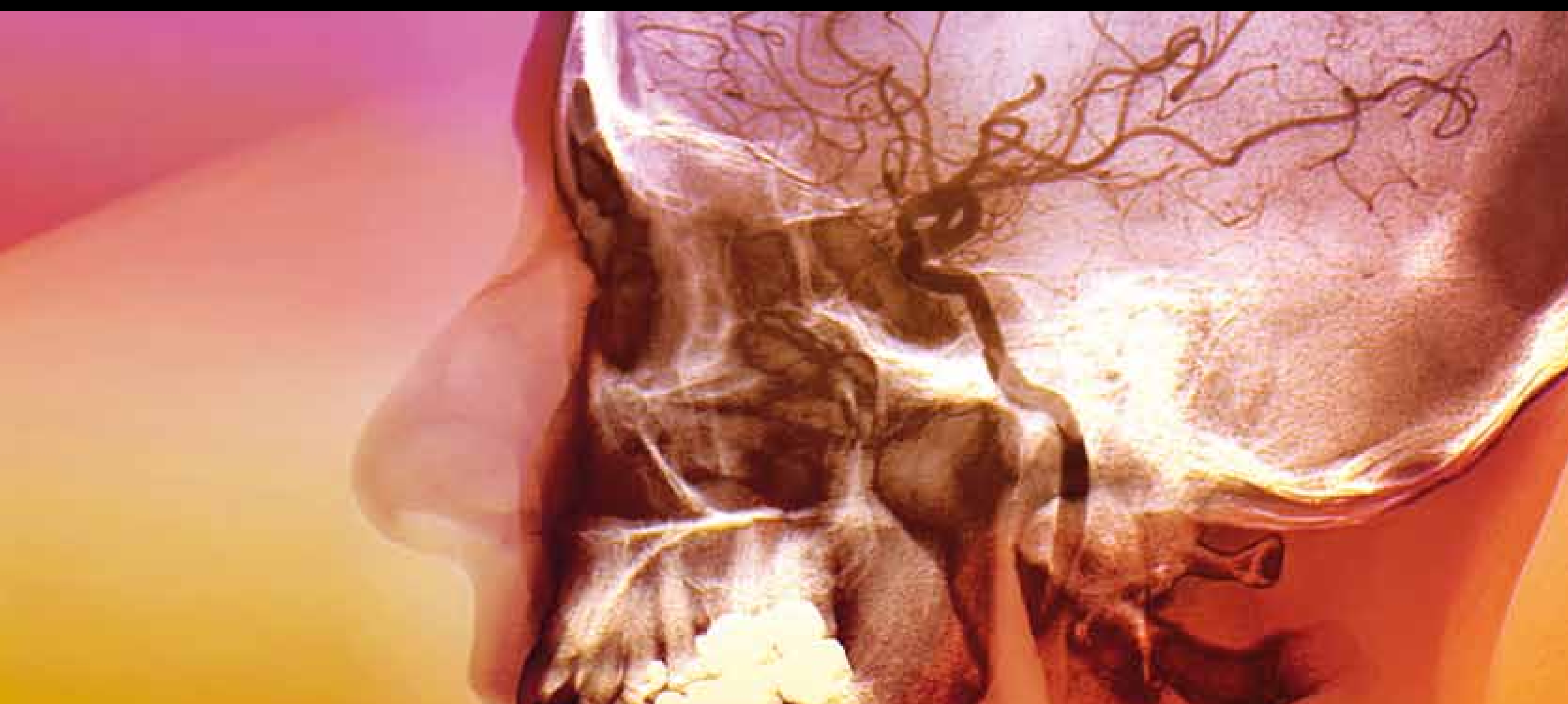
Stroke Research and Treatment

Motor Rehabilitation after Stroke

Guest Editors: Ching-yi Wu, Keh-chung Lin, Steven L. Wolf,
and Agnès Roby-Brami



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Editorial Board

Contents

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Editorial

Motor Rehabilitation after Stroke

Ching-yi Wu,[1] Keh-chung Lin,[2] Steven L. Wolf,[3,4,5,6] and Agnès Roby-Brami[7]

[1] *Department of Occupational Therapy and Graduate Institute of Behavioral Sciences, Chang Gung University College of Medicine, Taoyuan 33302, Taiwan*
[2] *School of Occupational Therapy, National Taiwan University College of Medicine, Taipei 10051, Taiwan*
[3] *Department of Rehabilitation Medicine, Center for Rehabilitation Medicine, Emory University School of Medicine, Atlanta, GA 30322, USA*
[4] *Department of Cell Biology, Center for Rehabilitation Medicine, Emory University School of Medicine, Atlanta, GA 30322, USA*
[5] *Health and Elder Care, Nell Hodgson Woodruff School of Nursing, Emory University, Atlanta, GA 30322, USA*
[6] *VA Rehab R&D Brain Rehabilitation Research Center, Gainesville, FL 32608, USA*
[7] *Department of Neurological Rehabilitation, Raymond Poincaré Hospital and Laboratoy of Neurophysics and Physiology, Paris Descartes University, 75270 Paris, France*

Correspondence should be addressed to Ching-yi Wu, cywu@mail.cgu.edu.tw

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Stroke is one of the most common conditions in adults that may cause impairment and disability. Motor impairments often persistently affect the daily function and quality of life among stroke survivors. Recently, a few novel interventions to improve motor impairment have evolved that make use of advances in neuroscience and neurobehavioral knowledge. These theory-driven approaches attempt to translate basic science research into novel clinical practice and build on methods to manipulate favorable plasticity changes within the brain in response to task-related training to augment motor recovery.

Developing a new clinical intervention may consist of four phases [1]: consideration of concept, development of concept, demonstration of concept, and proof of concept. The value of a phase I study is to learn how well an intervention can be applied, how patients respond to the intervention, to whom it ought to be given, what outcomes should be measured, and how its safety can be assured. Phase II studies aim to standardize the new treatment, compare efficacy against alternative treatments, and ensure that outcomes can be measured objectively and reliably. Phase III studies aim to optimize the treatment (dosage optimization) and enhance its practicality. Most of the papers published in this special issue are Phase I studies. An increase in Phase II and III studies is needed to improve stroke rehabilitation research and practice.

Among the five Phase I studies presented here, two assessed how well the intervention could be applied in patients with stroke. A. Reinthal and colleagues evaluated the effects of a novel activity-based gaming exercise that involved highly repetitive practice in stroke rehabilitation. S. B. Badia and M. S. Cameirão used 10 healthy individuals to test a neurorehabilitation training toolkit designed for stroke survivors in the home environment.

Three papers in this special issue addressed appropriate treatments for specific types of patients, for example, the degree of impairments or type of symptoms. This information can be used to maximize the benefits of specific interventions. Among these studies, C. Schuster and colleagues' study involved a qualitative, patient-centered study to address where, when, what, how, and why motor imagery can be used for stroke rehabilitation. F. Malouin and colleagues investigated the effect of the side of hemispheric lesion on temporal congruence between real and imagined movements and its link with working memory deficits in persons with chronic stroke. B. Langhammer and B. Lindmark demonstrated immediate and follow-up improvements after functional exercise between groups with high and low baseline functional level for a period of 36 months after stroke.

L. Chuang and colleagues' study of instrument evaluation examined the reliability of Myoton-3 myometer, a tool used to quantify muscle tone, elasticity, and stiffness in stroke patients. This study provided evidence for the psychometric soundness of myotonometric measurement. Also included in this special issue are two systematic reviews of optimal dosage of stroke motor rehabilitation.

To advance stroke motor rehabilitation, future research may translate concepts from basic sciences to clinical trials and heath care of patients with stroke. Issues relevant for study may include, but are not limited to, the following.

(i) What are the most beneficial interventions for specific types of patients under specific circumstances [2]?

(ii) What are the factors (e.g., the time for delivering a specific intervention, patient characteristics) that may affect treatment outcomes [3, 4]?

(iii) What are the fundamental mechanisms (neurophysiologic and biomechanical) that may underlie motor improvements?

(iv) How can bioengineered or robotic devices be optimally used to effectively manage motor impairment and disabilities?

(v) What are the optimal dosages for specific rehabilitation regimens [5]?

Continued research on these issues will lead to improved knowledge and practice guidelines for stroke rehabilitation.

Ching-yi Wu
Keh-chung Lin
Steven L. Wolf
Agnès Roby-Brami

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Clinical Study

Quantitative Mechanical Properties of the Relaxed Biceps and Triceps Brachii Muscles in Patients with Subacute Stroke: A Reliability Study of the Myoton-3 Myometer

Li-ling Chuang,[1] Ching-yi Wu,[2] Keh-chung Lin,[1,3] and Shih-yu Lur[2]

[1] *School of Occupational Therapy, College of Medicine, National Taiwan University, Taipei, Taiwan*
[2] *Department of Occupational Therapy and Graduate Institute of Clinical Behavioral Science, College of Medicine, Chang Gung University, Taoyuan, Taiwan*
[3] *Division of Occupational Therapy, Department of Physical Medicine and Rehabilitation, National Taiwan University Hospital, Taipei, Taiwan*

Correspondence should be addressed to Keh-chung Lin, kehchunglin@ntu.edu.tw

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Objective. Test-retest reliability of the myotonometer was investigated in patients with subacute stroke. *Methods*. Twelve patients with substroke (3 to 9 months poststroke) were examined in standardized testing position twice, 60 minutes apart, with the Myoton-3 myometer to measure tone, elasticity, and stiffness of relaxed bilateral biceps and triceps brachii muscles. Intrarater reliability of muscle properties was determined using intraclass correlation coefficient (ICC), the standard error of measurement (SEM), and the minimal detectable change (MDC). *Results*. Intrarater reliability of muscle properties of bilateral biceps and triceps brachii muscles were good (ICCs = 0.79–0.96) except for unaffected biceps tone (ICC = 0.72). The SEM and MDC of bilateral biceps and triceps brachii muscles indicated small measurement error (SEM% < 10%, MDC% < 25%). *Conclusion*. The Myoton-3 myometer is a reliable tool for quantifying muscle tone, elasticity, and stiffness of the biceps and triceps brachii in patients with subacute stroke.

1. Introduction

Abnormalities in muscle structure and properties are a common feature after stroke [1–3] and lead to poor controlled movement and functional disability [4]. Examining the mechanical properties of muscle is important in monitoring the stage of the pathologic processes of muscles [5, 6] and for assessing efficacy of therapeutic interventions [7]. The most widely used clinical assessment of muscle tone is the modified Ashworth scale (MAS), which assesses muscular resistance to passive movement [8, 9]. Nevertheless, the MAS uses subjective grading [9, 10], has poor reliability [9] and clustering of scores [11, 12], and lacks significant correlation with muscular stiffness after stroke [13, 14]. Therefore, an objective measurement tool with an excellent reliability and small measurement error for assessing the mechanical properties of muscle is necessary. Researchers have reported a new approach, the myotonometric measure, which was more sensitive and precise than the MAS to quantify muscle properties [15].

The prerequisites of a proper measurement are validity and reliability. Validity ensures that a measurement actually evaluates what it is intended to measure, and reliability is the extent of a consistent measurement outside of measurement error [16]. The validity of the myotonometer has been established in healthy individuals [17, 18], in patients with chronic pain in the anterior leg or dorsal forearm [19], in patients with upper motoneuron disorders [12], and in stroke survivors [20]. Myotonometric measurements of muscle stiffness showed an approximately linear increase with increasing electromyographic measurements of muscle activation and contractile force during voluntary isometric contraction, indicating tissue displacement during contracted conditions provided an indirect measure of muscle strength [17–19]. The linear relationship between muscle stiffness and force output suggested that the myotonometer was giving a valid recording of the muscle stiffness rather than that of the subcutaneous tissue [18]. The myotonometer quantified spasticity of the biceps brachii muscle and correlations between the myotonometric measurements of muscle tone and MAS were moderate to high in subjects with upper motoneuron disorders [12]. Differences of myotonometric measurements in relaxed and active muscle contraction were significantly related to total ankle stiffness quantified using a torque motor [20]. The significance of the association between these outcomes indicates that they measure similar constructs.

Previous studies have shown that myotonometry is reliable for healthy adults [18, 21, 22] and for various patient populations, including those with Parkinson's disease [23, 24], cerebral palsy [25, 26], musculoskeletal disorders [27, 28], and chronic stroke [29]. To date, however, only one study has examined the test-retest reliability of the myotonometer on the forearm muscles in patients with chronic stroke [29], which limits its use in patients with stroke. Pathologic progressions in muscles may differ across various diseases and stage of disease; thus, the reliability of the myotonometer should be established for patients with subacute stroke.

Patients with stroke have increased passive biceps brachii tone [12] and stiffness [14]. Biceps and triceps brachii muscle paresis and biceps brachii cocontraction during voluntary reaching have shown significant correlations to decreased motor performance, indicating that these two muscles are good predictors of the motor performance of the upper extremity [14]. Therefore, it is important to explore the reliability of the myotonometer on the biceps brachii and triceps brachii muscles.

The present pilot study investigated the intrarater reliability of a hand-held myotonometry device (Myoton-3) for measuring muscle properties of bilateral biceps brachii and triceps brachii muscles in patients who had experienced a first-ever stroke within 3 to 9 months before enrollment. This time window is the period in which most available standard therapeutic interventions have been completed and the opportunity for spontaneous recovery to occur is attenuated [30]. Findings from the present study can contribute to a better understanding of mechanical properties of elbow muscles in patients with subacute stroke and may also provide diagnostic and therapeutic implications.

2. Methods

2.1. Participants. We recruited 12 participants (8 men and 4 women) with a mean age of 51.19 years. Table 1 summarizes participant characteristics. Inclusion criteria were (1) a first-ever stroke of 3 to 9 months before recruitment, (2) Brunnstrom stage III or above in the proximal and distal part of the arm [31], (3) no severe spasticity in the paretic arm (MAS ≤ 2) [8], (4) no cognitive deficits (Mini-Mental State Examination score ≥ 24) [32], and (5) no other neurologic, neuromuscular, or orthopedic disease. Institutional Review Board approval was obtained from the participating sites and written informed consent was obtained from all participants before data collection.

Table 1: Characteristics of the participants ($n = 12$).

Characteristic	
Sex, *n*	
Male	8
Female	4
Age, mean (SD), year	51.19 (11.02)
Side of hemiplegia, *n*	
Right	7
Left	5
Months after stroke onset, mean (SD)	6.58 (1.38)
Brunnstrom stage of upper limb, median (range)	
Proximal part	4.5 (3.5–5)
Distal part	4.5 (3.5–5.5)
Fugl-Meyer Assessment for upper limb, mean (SD)	47.92 (6.33)
Mini Mental State Exam scores, mean (SD)	27.50 (3.26)

SD: standard deviation.

2.2. Testing Procedures. Myotonometric measurements in bilateral biceps and triceps brachii muscles were performed at rest, using the Myoton-3 myometer (Muomeetria AS, Tallinn, Estonia) by a senior occupational therapist (Figure 1) [33]. Before measurement, participants were informed standard measurement procedure. Measurements were done with the participant lying supine for biceps brachii and side lying for triceps brachii in a relaxed manner, with the participants' arms at their sides and forearms between pronation and supination. The location of the measured muscles was first determined on the unafffected side, thereafter on the affected side. The participant was requested to make an effort by applying resistance with the biceps brachii or triceps brachii to the therapist's hand and at the same time the measuring points for the biceps brachii and triceps brachii were identified by the therapist according to bone prominence and palpation. The middle part of the muscle belly is suggested as the particular measuring point [18, 34], which was marked with a marker in order to replicate the positioning for the subsequent hour used for the reliability measures. For example, the measuring point for the biceps brachii was at the long head, lateral part of muscle, in the middle of arm; and that for the triceps brachii was at the medial head of muscle, in the middle part of arm [35]. The muscles of the unaffected side of the body were measured first. After participants were instructed to relax their muscles maximally, the testing end of the Myoton-3 was placed perpendicular on the skin surface overlying the measuring points of the respective bilateral biceps brachii and triceps brachii. Three consecutive measurements with roughly 1 second in between were taken in each muscle, and the average value was used for later analysis. The entire test session was repeated 60 minutes after the first session with the same procedure, same position, and same measuring point.

The Myoton-3 myometer exerts a short mechanical pulse on the tested muscle, which causes muscle to be deformed for a short interval. The muscle responds to the mechanical stimulus in the form of damped oscillations recorded by an acceleration transducer on the testing end, and 3 parameters

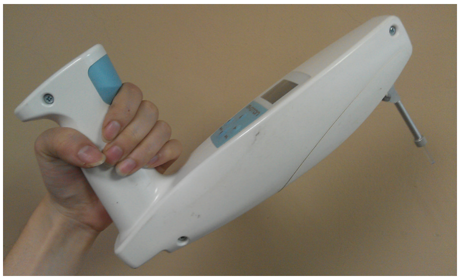

Figure 1: The Myoton-3 myometer.

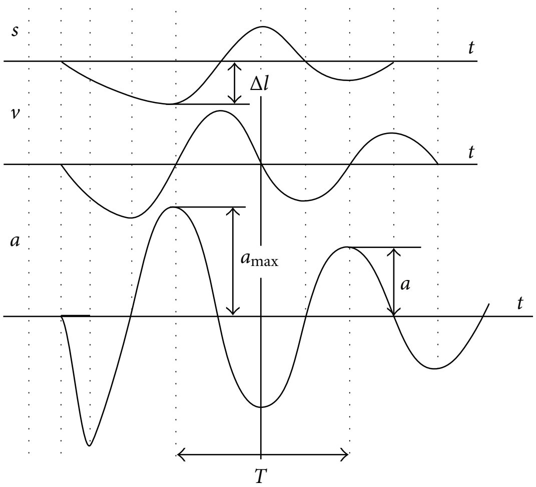

Figure 2: Damped oscillations of the muscle show displacement (s), velocity (v), and acceleration (a) in myotonometric measurements. T is the oscillation period, a_{max} is the maximal amplitude of oscillation, and Δl is the maximal deformation depth of the muscle.

are calculated from the curve (Figure 2). Three mechanical properties of the muscle tissue are (1) the natural oscillation frequency (Hz), (2) the logarithmic decrement of damping oscillations, and (3) the stiffness (N/m) [15, 27, 34].

The frequency of the damped oscillations characterizes the muscle tone, the mechanical tension in a relaxed muscle. The higher the value, the more tense is the muscle. The frequency of the damping was calculated as (Frequency (Hz) = $1/T$), where T is the oscillation period in seconds (Figure 2). The range of values of the oscillation frequency is usually 11 to 16 Hz in the functional state of relaxation and 18 to 40 Hz in contraction, depending on the muscle [34]. The logarithmic decrement of the damping oscillations characterizes muscle elasticity. The logarithmic decrement of damping was calculated as (Decrement = $\ln(a_{max}/a)$), where a_{max} is the maximal amplitude of oscillation and a is the oscillation amplitude (Figure 2). The decrement values are usually 1.0 to 1.2, depending on the muscle. At the point of maximum compression of the muscle being measured, the corresponding acceleration (a_{max}) characterizes the resistance of the muscle to the force deforming the muscle [28]. Stiffness was calculated as (Stiffness = $a_{max} \times m/\Delta l$), where m is the mass of the testing end of myometer (kg); a_{max} is the maximal acceleration of oscillation (m/s^2); Δl is the deformation depth of the muscle mass (Figure 2) [18]. The usual range of stiffness values is 150 to 300 N/m for resting muscle and may exceed 1000 N/m for contracted muscles [34].

Operational Definition and Functional Role of Muscle Tone, Elasticity, and Stiffness. Muscle tone, elasticity, and stiffness quantify the functional state of the muscle [27, 28]. Muscle tone involves active nervous-system-stimulated tone and passive (resting) intrinsic viscoelastic tone [21, 36, 37]. From the biomechanics perspective, muscle tone is a mechanical tension in the relaxed muscle [34]. Passive muscle tone is defined as the passive muscle tonus or tension that derives from its intrinsic viscoelastic properties without contractile activity [36, 37]. The functional roles of passive muscle tone are maintaining balance, stability, and posture, providing adequate blood circulation to the muscle and achieving energy-efficient costs for prolonged duration without fatigue [34, 36]. Increased muscle tone disturbs the blood supply in the muscle to diminish oxygen transportation, which might relate to pain, lowered motor performance, overload, and so on [34].

Muscle elasticity is the ability of the muscle to restore its initial shape after contraction, which is inversely proportional to the decrement [34]. Muscle elasticity increases as the decrement decreases. Muscle elasticity is important in using muscle energy and increasing blood circulation volume during the effort. Decreased muscle elasticity brings on easier fatigability and limited speed of movement [34].

Muscle stiffness is a muscle's ability to resist the deformation caused by external forces [36–38]. The speed and ease of the movement performed by the agonist muscle is associated with the stiffness of the antagonist muscle. When a muscle becomes more stiff, greater force is required from the antagonist, which decreases the energy expenditure economy of movement [34].

2.3. Data Analysis. Results of myotonometric measurements are presented as mean and standard deviation (SD). Intrarater reliability was analyzed through the intraclass correlation coefficient (ICC), standard error of measurement (SEM), SEM%, minmal detectable change (MDC), and MDC%. The Kolmogorov-Smirnov test was used to examine whether the tested parameters satisfied conditions for normal distribution. The ICC was calculated using a 2-way mixed-effect model, with an agreement coefficient and average measure. The ICC determines the degree of consistency and agreement between repeated measurements [39], with an ICC exceeding 0.75 indicating excellent reliability [16]. The SEM represents the smallest change between 2 time points that provides an indication of within-subject variability in repeated tests and determines the extent of measurement error. The MDC represents the magnitude of change necessary to exceed the measurement error of test-retest measures that indicates a true statistical change at a certain confidence interval (CI) level for a single individual [39–41]. The SEM was calculated as (SEM = $SD_{pooled} \times \sqrt{(1 - ICC)}$), where SD_{pooled} is the SD for all observations from test sessions 1 and 2, and ICC is the test-retest reliability coefficient [42]. The SEM% indicates the relative amount of measurement error independent of the units of measurement

Table 2: Myotonometric measurements of the biceps and tricpes brachii muscles[a].

Muscle	Variable	First session		Second session	
		Affected	Unaffected	Affected	Unaffected
Biceps brachii	Tone (Hz)	11.72 (1.83)	12.03 (1.65)	11.44 (1.63)	11.82 (1.32)
	Elasticity	1.70 (0.30)	1.52 (0.38)	1.63 (0.30)	1.46 (0.32)
	Stiffness (N/m)	223.42 (31.68)	225.50 (30.36)	217.08 (27.19)	217.25 (26.64)
Triceps brachii	Tone (Hz)	11.23 (2.05)	11.75 (2.42)	10.76 (2.53)	11.18 (3.25)
	Elasticity	1.78 (0.51)	1.64 (0.37)	1.80 (0.50)	1.73 (0.43)
	Stiffness (N/m)	197.08 (28.23)	192.08 (33.22)	195.50 (28.79)	189.08 (55.06)

[a]Values are reported as means (standard deviations).

Table 3: Test-retest reliability of myotonometric measurements of the biceps and tricpes brachii muscles.

Muscle	Variable	ICC (95% CI)		SEM (SEM%)		MDC_{90} (MDC_{90}%)	
		Affected	Unaffected	Affected	Unaffected	Affected	Unaffected
Biceps brachii	Tone (Hz)	0.96 (0.86–0.99)	0.72 (0.25–0.92)	0.34 (2.93%)	0.77 (6.45%)	0.79 (6.82%)	1.79 (15.01%)
	Elasticity	0.85 (0.54–0.96)	0.94 (0.80–0.98)	0.12 (6.92%)	0.09 (6.04%)	0.27 (16.26%)	0.20 (13.42%)
	Stiffness (N/m)	0.91 (0.70–0.97)	0.87 (0.59–0.96)	8.81 (4.00%)	10.34 (4.67%)	20.52 (9.31%)	24.09 (10.88%)
Triceps brachii	Tone (Hz)	0.90 (0.68–0.97)	0.89 (0.65–0.97)	0.70 (6.36%)	0.92 (8.04%)	1.63 (14.83%)	2.14 (18.67%)
	Elasticity	0.93 (0.76–0.98)	0.93 (0.76–0.98)	0.13 (7.26%)	0.10 (5.95%)	0.30 (16.75%)	0.23 (13.69%)
	Stiffness (N/m)	0.79 (0.40–0.94)	0.79 (0.40–0.94)	12.69 (6.46%)	20.44 (10.72%)	29.56 (15.05%)	47.62 (24.98%)

ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error of measurement; SEM%: SEM divided by the mean of all measurements from the two sessions and multiplied by 100%; MDC: minimal detectable change; MDC%: MDC divided by the mean of all measurements from the two sessions and multiplied by 100%.

and represents the threshold for the smallest change that shows a real change for a group of participants, which was defined as (SEM% = (SEM/mean) × 100), where *mean* is the mean for all observations from the 2 sessions [43, 44].

The MDC_{90} was used to determine whether the change score of a participant is real at the 90% confidence level, which was calculated as ($MDC_{90} = 1.65 \times \sqrt{2} \times \text{SEM} = 1.65 \times \sqrt{2} \times \text{SD}_{\text{pooled}} \times \sqrt{(1 - ICC)}$), where 1.65 is the two-tailed tabled z value for the 90% CI, and $\sqrt{2}$ represents the variance of two measures [42]. The MDC_{90}% represents the relative amount of measurement error and a relative true difference between repeated measurements over time in a participant, which was defined as ($MDC_{90}\% = (MDC_{90}/\text{mean}) \times 100$), where *mean* is the mean for all measurements from 2 sessions [43, 44].

Generally, differences between 2 measurements that are larger than the SEM and MDC_{90} can be attributed to a real change or beyond measurement error [45]. The smaller the SEM and MDC_{90}, the greater the reliability [41].

3. Results

The study participants were 12 patients who met the selection criteria. Participants were a mean age of 51.19 years, and the average time after stroke onset was 6.58 months. Detailed characteristics of the participants are reported in Table 1. Descriptive statistics of the myotonometric measurements in the 2 test sessions are reported in Table 2. The values of muscle tone and stiffness in both biceps and triceps brachii muscles were within the range in the functional state of relaxation. Results of the Kolmogorov-Smirnov test demonstrated the myotonometric measurements were normal distribution.

As detailed in Table 3, the ICCs for bilateral biceps and triceps brachii muscles exceeded 0.75 (ICCs = 0.79–0.96), except for unaffected biceps brachii tone (ICC = 0.72), indicating that the myotonometric measurements had excellent intrarater reliability.

The SEM (SEM%) of the bilateral biceps and triceps brachii muscles was from 0.34 to 0.92 Hz (2.93%–8.04%) for the tone, 0.09 to 0.13 (6.04%–7.26%) for the elasticity, and 8.81 to 20.44 N/m (4.00%–10.72%) for the stiffness, with affected biceps brachii tone being the smallest and unaffected triceps brachii stiffness being the largest. The MDC_{90} (MDC_{90}%) of the bilateral biceps and triceps brachii muscles was from 0.79 to 2.14 Hz (6.82%–18.67%) for the tone, 0.20 to 0.30 (13.42%–16.75%) for the elasticity, and 20.52 to 47.62 N/m (9.31%–24.98%) for the stiffness (Table 3). Generally, the SEM% values were below 10% and the MDC_{90}% values were below 25% in the muscle properties of the biceps brachii and triceps brachii, except for the SEM% of the unaffected triceps brachii stiffness, representing a small amount of measurement error [44]. The SEM (SEM%) and MDC_{90} (MDC_{90}%) of the biceps brachii appeared to be smaller than those of the triceps brachii muscle.

4. Discussion

This study investigated intrarater reliability of the Myoton-3 myometer for the elbow muscles in patients with subacute stroke. The results showed good intrarater reliabilities of the myotonometric measurements, with high agreement and small measurement error in repeated tests.

This pilot study showed that the myotonometer was highly reliable for measuring biceps and triceps brachii muscles in patients with subacute stroke. The ICC values were high, indicating excellent reproducibility of the Myoton-3 between successive sessions of assessment. This was in agreement with results of previous interday reliability studies in different muscle groups and study populations [18, 21, 22, 24–27]. In a previous study, looking at the interday reliability of the Myoton-3 myometer in 10 healthy young volunteers who were retested after 2 days, the relaxed biceps femoris muscle exhibited a moderate ICC score (0.54–0.73) [21]. Another interday reliability study by Bizzini and Mannion repeated the same tests of day 1 on day 2 for measuring relaxed muscle stiffness of the rectus femoris, vastus lateralis, biceps femoris, and gastrocnemius using the Myoton-2 myometer in 10 healthy volunteers. The results showed good to excellent test-retest reliability for all muscles (ICCs 0.80–0.93), except for the vastus lateralis (ICC 0.40) [18].

The ICC cannot detect systematic errors [39], however, and assessments of within-subject variability in the test-retest measurements are necessary to evaluate reliability comprehensively [26]. A good myotonometric measure should present small measurement errors and be sensitive to identify the smallest real changes in repeated measurements. Establishing reliability of measures is important not only for repeated measurements with sound stability but also to identify changes over time [46].

The SEM and MDC_{90} provide the values of the measurement error between repeated tests for a group and for an individual, respectively. Clinicians and researchers can use the SEM and MDC_{90} values to determine whether a change in a group or in an individual is statistically significantly real [47, 48]. That is, the real change in a patient should exceed the MDC_{90} of the measure. The SEM (SEM%) and MDC_{90} (MDC_{90}%) of the bilateral biceps and triceps brachii muscles in this study were small, indicating small measurement error [44]. It should be noted that the SEMs of tone and stiffness in the biceps and triceps brachii muscles were consistently higher in unaffected side compared to affected side. The ICCs of tone and stiffness in the unaffected biceps and triceps muscles were lower than those in the affected ones. This was similar to lower intrarater reliability of measurements of the unaffected biceps than that of the affected biceps brachii in children with spastic-type cerebral palsy [26] and lower intrarater reliability of the relaxed biceps brachii than the isometrically contracted biceps brachii in healthy adults [22]. The reasons for this were not clear, but might be that the participants had difficulty in remaining relaxed when the testing end of the Myoton-3 myometer was first placed on the unaffected muscles.

The SEM% and MDC_{90}% are independent of the units of measurement, which are more easily interpreted and appropriately compares the amount of random error among muscle groups and properties [44]. The results of SEM and MDC in the present study can be used as a reference for the Myoton-3 to help clinicians and researchers identify small, real changes of muscle properties of the biceps and triceps brachii muscles between repeated measurements for patients with substroke.

This study needs to account for the following limitations. First, a variety of factors that may affect resting muscle tone in patients with subacute stroke include the location of stroke lesion, the severity and type of stroke, body positioning, level of tension in synergic and antagonist muscles, level of test anxiety, and time when the test was administered. Only 12 patients with subacute stroke who demonstrated a low level of spasticity and were without cognitive impairment were included in this pilot study, which may limit the generalizability of our findings. Future studies that consider possible factors that may affect test performance using a larger and more diverse group of patients with stroke are needed to validate our findings and to promote the clinical utility of the myotonometer.

Second, passive muscle tone as measured by the electromyography or isokinetic dynamometer has not been assessed and this is an acknowledged limitation of the present study. Additionally, passive muscle properties in the relaxed state cannot represent functional evaluation during contracted state. The concurrent measurement of muscle properties in relaxation and under contraction with a myotonometer and electromyography or dynamometer is suggested for future studies.

Third, the myotonometry method is not applicable for the following conditions: thin muscle, muscle with small mass, obese persons (BMI $> 30\,\mathrm{kg{\cdot}m^{-2}}$), patients suffering from severe pain, muscle which are palpable in small volume, and muscles which are located under other muscles [34]. In this pilot study, we did not record the arm girth, BMI, and fatty tissue to consider the obesity; therefore, future study is recommended to take this issue into account.

Finally, to enhance the applicability and interpretability of the myotonometric measurements, future studies to estimate minimal clinical important differences are warranted to determine the degree of meaningful change to patients with stroke.

5. Conclusion

Our pilot study showed that the Myoton-3 myometer has good intrarater reliability in measuring the mechanical properties of bilateral biceps brachii and triceps brachii muscles with high agreement and low thresholds to detect real changes in patients with stroke. The findings indicate that the Myoton-3 myometer is a reliable tool for quantifying the muscle tone, elasticity, and stiffness of elbow flexor and extensor muscles in patients with subacute stroke. Further research with larger and divergent groups of patients with stroke is needed to confirm the findings of our study.

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Research Article

The Neurorehabilitation Training Toolkit (NTT): A Novel Worldwide Accessible Motor Training Approach for At-Home Rehabilitation after Stroke

Sergi Bermúdez i Badia and M. S. Cameirão

Madeira Interactive Technologies Institute, Universidade da Madeira, Campus Universitario da Penteada, Madeira, 9020-105 Funchal, Portugal

Correspondence should be addressed to Sergi Bermúdez i Badia, sergi.bermudez@m-iti.org

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After stroke, enduring rehabilitation is required for maximum recovery, and ideally throughout life to prevent functional deterioration. Hence we developed a new concept for at-home low-cost motor rehabilitation, the NTT, an Internet-based interactive system for upper-limb rehabilitation. In this paper we present the NTT design concepts, its implementation and a proof of concept study with 10 healthy participants. The NTT brings together concepts of optimal learning, engagement, and storytelling to deliver a personalized training to its users. In this study we evaluate the feasibility of NTT as a tool capable of automatically assessing and adapting to its user. This is achieved by means of a psychometric study where we show that the NTT is able to assess movement kinematics—movement smoothness, range of motion, arm displacement and arm coordination—in healthy users. Subsequently, a modeling approach is presented to understand how the measured movement kinematics relate to training parameters, and how these can be modified to adapt the training to meet the needs of patients. Finally, an adaptive algorithm for the personalization of training considering motivational and performance aspects is proposed. In the next phase we will deploy and evaluate the NTT with stroke patients at their homes.

1. Introduction

There are about 16 million new strokes per year worldwide [1], and about 5 million of the survivors will sustain motor and/or cognitive impairments for the rest of their lives [2]. This situation leads to high societal costs in medical care and rehabilitation expenses, with annual costs above €38 billion in Europe [3]. Collaterally, there is decreasing participation of these patients in professional and social life since stroke survivors frequently suffer from mood disorders or depression [4, 5]. Therefore, due to its direct and indirect effects, stroke is one of the main contributors for the worldwide burden of disease [6, 7].

Following stroke, enduring rehabilitation is needed for maximum recovery. This requires long-term hospitalization or outpatient rehabilitation, a situation that is extremely demanding both for patients and national health systems. In fact, there is a growing interest towards early supported discharge from hospitals and at-home rehabilitation [8, 9]. Nonetheless, despite outpatient rehabilitation programs, it is generally assumed that the full potential for recovery is reached in the first 6 months after stroke, with patients then being discharged from rehabilitation [10]. This might be problematic as there is evidence that the brain remains plastic at later stages post stroke, meaning that there can still be place for additional recovery [11, 12]. Ideally, stroke patients should undergo maintenance rehabilitation throughout life to prevent functional deterioration. Indeed, a significant decline in mobility after rehabilitation discharge is expected in one fifth of chronic patients, having a direct impact in performing activities of daily living (ADL) [13]. Thus, there is a need to find solutions to provide patients with tools that allow them to have enduring rehabilitation at their homes.

In recent years, novel technology-based systems have been developed for at-home stroke rehabilitation [14–23]. Although the price of these systems is lower than standard technology-based rehabilitation devices, most of them are still unaffordable for the majority of patients. Moreover, these systems usually rely on particular hardware components, require elaborate setups, and/or need remote guidance, which makes them difficult to use particularly if we take into account that most of the stroke patients are elderly.

To provide patients with effective, uncomplicated, and inexpensive rehabilitation at their homes, we have developed the Neurorehabilitation Training Toolkit (NTT), a PC-based interactive system for upper-limb rehabilitation. The NTT makes use of well-established state of the art requirements for effective rehabilitation after stroke, providing training that is frequent, reiterative, and task specific [24–26], and that presents feedback on performance and outcomes [27–29]. These characteristics are achieved through the use of game-like tasks displayed on a standard computer, designed to address the specific upper-limb deficits of stroke patients.

In the last few years, a number of standard commercial videogames have been used for stroke rehabilitation [30, 31]. Although the concept is valid, these are ad hoc solutions since these games were designed for a different target population, therefore not fully addressing the needs and capabilities of the patients. In previous work we developed and evaluated a game for rehabilitation that provides personalized training that is adjusted to the individual capacities of the patients [32]. In this way, patients can undergo a challenging training task designed towards their specific motor deficits (thus avoiding boredom), without falling beyond the patients capabilities which could lead to frustration. We have shown that the use of such an approach as a complement to standard rehabilitation leads to improved and accelerated recovery in acute stroke patients [18]. With the NTT, we go one step further because we are able to assess movement kinematics and psychometrics that allow the personalization of a number of training objectives. These objectives include the range of motion and movement smoothness.

The NTT consists of widely available home-based technologies, namely, a PC or laptop, two mice, and an Internet connection. This configuration makes the system uncomplicated and rather inexpensive, and therefore accessible and affordable for most patients. The use of an Internet connection is twofold. On one hand, the game "lives" online—for an easy upgradeability of the software—and requires no installation. On the other hand, it can be used to monitor and assess the progress of patients remotely. Additionally, the NTT encompasses automatic questionnaires to assess the usability, engagement, and acceptance of the training tasks, as well as to measure the training impact on the performance of ADLs. Here we present the design concepts behind the NTT, the results of a pilot study where we developed a novel personalization algorithm based on functional motor outcomes, and demonstrate the NTT capabilities as an assessment and monitoring tool tested with healthy users. Due to its simplicity and innovative features, we believe that the NTT is a powerful tool that will give patients access to an affordable, effective, and long-term rehabilitation at their homes, allowing them to maximize and sustain recovery while increasing their overall quality of life.

2. Materials and Methods

The NTT is a software-based motor training toolkit that is accessed and executed from Internet as a web applet by means of an Internet browser (Figure 1(A)). NTT has been verified to work with the most commonly used browsers such as Internet Explorer, Google Chrome, Safari, Firefox, and Opera. In this context, the web browser serves as the interface to the training toolkit, allowing its execution without needing local installation or additional software besides the NTT applet itself. In addition to a PC with an Internet connection, the NTT user needs a working email account for communication and user support if needed.

On the hardware side, the NTT can run on any modern computer with Windows O.S. (Windows XP, Vista, or 7) (Figure 1(B)). The only requirement for the PC is to have two mice connected to it. Computer mice are widespread, reliable, and extremely low-cost devices that will serve to track the physical movements of the arms of the patients, which in turn will be used to interact with the NTT. Technically, the main advantage of the NTT is the ability to capitalize on existing common hardware to deliver personalized and continued training. This is achieved by the low hardware requirements and the accessibility of our online system (Figure 1(C)). Internet serves as the distribution channel for the NTT, offering its training and other advantages to any patient anywhere in the world with access to a PC and an Internet connection. Furthermore, NTT upgrades are immediately deployed to the user's home without requiring action from their side. The NTT can be accessed at http://neurorehabilitation.m-iti.org/NTT/.

Our web services serve a threefold mission: *instruction*, *training* and *feedback*. The NTT site provides detailed instruction on how to use and operate the NTT. After giving informed consent, access to the NTT training is granted. The NTT runs as an embedded application on our site and delivers the training, logs data, and communicates with patients (Figure 1(D)). A remote data server is used to store log files after each training session containing relevant information such as the training date, user ID, data on the physical movements during training, game events, performance measures, and hardware configuration. Email services are used to communicate access codes and relevant user questionnaires after specific NTT training sessions.

2.1. NTT Game Training Scenario. The NTT web application was developed with the Python programming language using the open source game engine Panda3D (http://www.panda3d.org), which is maintained by Carnegie Mellon University. NTT is designed along neuroscientific and therapeutic guidelines for stroke rehabilitation based on a number of concepts: relevance of training to ADLs, neuroscientific principles of recovery, narrative, personalization or individualization, augmented feedback, and engagement.

2.1.1. Training Rational. After stroke, the recovery of the upper-limb functionality is essential for the recovery of the capacity of performing activities of daily living (ADL).

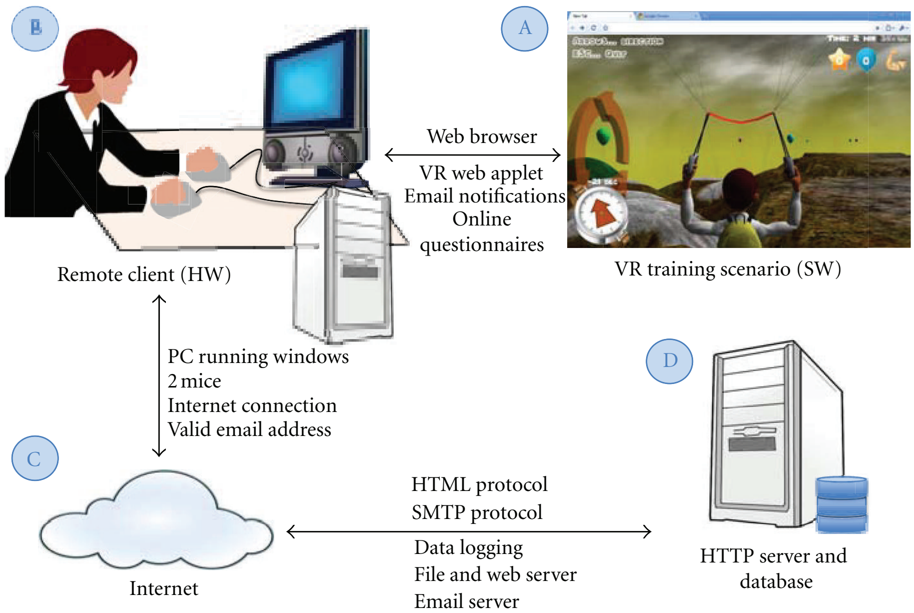

Figure 1: Neurorehabilitation Training Toolkit system architecture. (A) A web browser is used to access the application and its instruction at http://neurorehabilitation.m-iti.org/NTT/ (B) NTT can be executed on any modern PC equipped with two mice and an internet connection. (C) The NTT software is accessed freely from Internet, where the NTT servers are located. (D) A number of remote servers host the NTT site, the application itself, and are used to log user data.

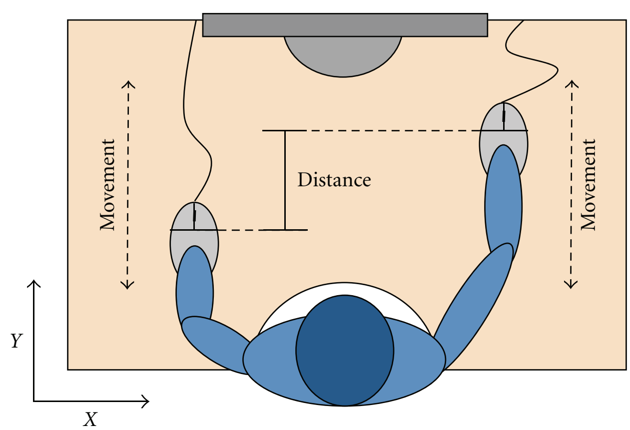

Figure 2: Sketch of the NTT-bilateral training task. Two mice track the position of right and left hands. The training consists of bilateral and coordinated displacement of the arms in the Y axis to change the heading direction of the NTT-virtual glider. The distance between hands in the Y axis defines the direction and the turning speed. See text for further information.

The ability of a stroke survivor to perform ADLs determines his/her level of independence to a great extent and therefore the need of specialized care, dependence on relatives, and societal burden [33]. Hence, the improvement of upper-limb function is a priority after stroke. Effective therapies for motor rehabilitation support the notion of training intensity, frequency, and task-specificity as being determinant outcome factors [25, 34, 35]. However, patients do not always have access to the ideal training frequency and intensity. In addition, the training specificity towards the needs of the patient appears to be of special relevance since it optimizes the training outcome [36]. Consequently, an effective upper-limb training paradigm should be based on training intensity, frequency, iteration, task specificity, and personalization of training to the patient's needs. NTT exploits the above-mentioned principles in a game-like experience where patients are confronted with a virtual scenario that requires them to repeatedly perform physical movements of varying intensity in order to complete a task. The NTT training task is performed on a tabletop (Figure 2).

With continuous research, more data about the post-stroke brain mechanisms are becoming available which support the claim that neuronal plasticity is the main contributor for recovery [37–40]. Plasticity is a life-long property of the brain that allows cortical networks to reorganize and regain lost functionality, even many years after stroke [11, 41]. Recent findings show how the reorganization of perilesional and contralesional cortical networks contributes to the recruitment of functional corticospinal fibers, which is vital for recovery [39, 42]. Therefore, novel rehabilitation approaches should be designed to capitalize on brain plasticity to regain motor function by means of a functional reorganization of the cortical networks. It is widely established in the rehabilitation literature that training frequency and intensity are effective drivers for cortical reorganization [34, 35, 43]. However, more recent neuroscientific findings should also be integrated in current rehabilitation praxis. This is the case of approaches based on the Mirror Neuron System (MNS), a population of neurons located in premotor and parietal cortical areas that have particular properties that make them good candidates to mobilize plasticity, and for motor learning in general

[44, 45]. The MNS is also known as the action recognition system because of its properties. These neurons are active both during the performance of meaningful and goal-oriented motor actions and the passive observation of those actions [46, 47]. Thus, this is a convenient neural system that can be exploited to activate motor-related areas and therefore to mobilize cortical plasticity by means of the observation of motor actions [48, 49]. Several motor rehabilitation approaches capitalize on this system to enhance or speed up recovery [32, 50, 51]. In a previous randomized controlled trial, we have shown that a VR system based on this principle speeds up recovery [18] in terms of motor function as measured by the Fugl-Meyer scale [52] and in ADLs as assessed by the Chedoke Arm and Hand Activity Inventory (CAHAI) [53]. Consequently, and in line with our previous work, we have integrated those neuroscientific aspects in the NTT by means of the presentation of a virtual character whose limbs perform meaningful goal-oriented actions that are triggered by and correlated with the physical movements of the arms of the patient. The combination of VR and goal-oriented actions has already been shown to activate the MNS and related motor areas, therefore facilitating functional cortical reorganization [50].

2.1.2. Training Task. In its current form, the NTT training task requires patients to be able to read, and not to have major cognitive deficits and seizures, sensory aphasias, or other perceptual problems that could impede the understanding of the task. Our training consists of a bilateral task that requires practicing range of motion and movement coordination. Several reasons support the choice of this particular task. First, a home-based training has to allow for a gradual functional integration and use of the paretic arm in the completion of tasks. Thus, our bilateral training task allows the patient to support the paretic arm with the nonparetic one when the task is too demanding. As such, our training task is also appropriate for hemiplegic patients with severely reduced mobility or motor control. Second, although evidence on the advantage of bilateral training when compared to unilateral training is limited [54], there are a number of findings that support its use [55, 56]. For instance, nowadays it is widely accepted that bimanual coordination is a largely distributed brain process, and therefore its training engages motor areas to a larger extent [57]. Moreover, since most patients manifest some degree of bimanual coordination deficit, bimanual coordination training is recommended to be part of any rehabilitation program [58]. Further, there is increasing evidence that bilateral training has a particularly beneficial effect in patients with low Fugl-Meyer motor scores, whereas it is as effective as unilateral training in well-recovered patients [55, 59].

The NTT bimanual training exercise is performed on a tabletop, providing arm support against gravity, what widens the spectrum of patients who can use it. The patient's hand movements are tracked by means of two computer mice that the patient is manipulating (Figure 2). The interaction with real objects has been shown to elicit better kinematics [60]. The physical movements of the patient are then used to control the movements of the arms of an avatar that is displayed on the computer's screen. The avatar arms control the steering direction of a glider that flies forward at a constant speed, accumulating collectable objects. The turning speed of the glider (α deg/sec) is defined as a function of the distance between mice (Figure 2):

$$\alpha = \text{gain} \cdot \left(Y_{\text{Right}} - Y_{\text{Left}}\right), \quad (1)$$

where Y_{Right} and Y_{Left} indicate the Y position of right and left mice, respectively, and gain is a factor that modulates the turning speed of the avatar.

2.1.3. Gaming Concepts. The glider control task was chosen due to the bimanual and intuitive nature of the control mechanism, the built-in control system that allows supporting the paretic arm actions with the nonparetic arm, the slow movement dynamics, and the pleasantness of a flying experience.

Improving on previous work, we decided to add a narrative element to the NTT since a flat and static virtual training task can make training monotonous and eventually limit the patient's engagement. Consequently, NTT exploits a simple narrative structure to build a story around the training task to increase the engagement of patients, facilitate the comprehension of the training objectives, and, most importantly, to deliver a clear sense of progress. This simple narrative is based on Freytag's classic concept of play and counter-play [61]. Play in our case describes how our player affects the world (an exciting force or rise), and counter-play how the world affects the player (a tragic force or decay). We created a sequence of plays and counter-plays that narrate the journey of our virtual character through an unknown environment that culminates with him finding home. The game structure includes a tutorial of the game, and a series of game levels/environments that lead the way to a narrative climax when home is reached (Figure 3(a)). In order to reach home, the avatar has to collect flying objects that enable him to complete the different game levels. Different game elements are used to shape the narrative curve; these include the task difficulty, presence of control disturbances, the choice of the color palette, the design of the environment itself, the choice of music and its rhythm, and the usage of the view/camera perspective.

In addition to the narrative component, the NTT makes extensive use of feedback using multiple and redundant feedback modalities to ensure that the patient understands the task and is positively rewarded for his/her accomplishments [28, 62]. For instance, on-screen pictorial instructions and a compass are used to indicate the direction and physical movements that are needed in order to get to the target. The current item to be collected is clearly indicated by a large moving arrow. To help the patient in the task, both the target arrow and the compass head turn from red into green when the avatar is correctly aligned in direction to the target. Every collected item is rewarded with a positive visual and auditory feedback. Collectable items are divided into easy (balloons) and hard (stars) ones, which are counted as separate scores. Finally, the total distance moved by the arms during training

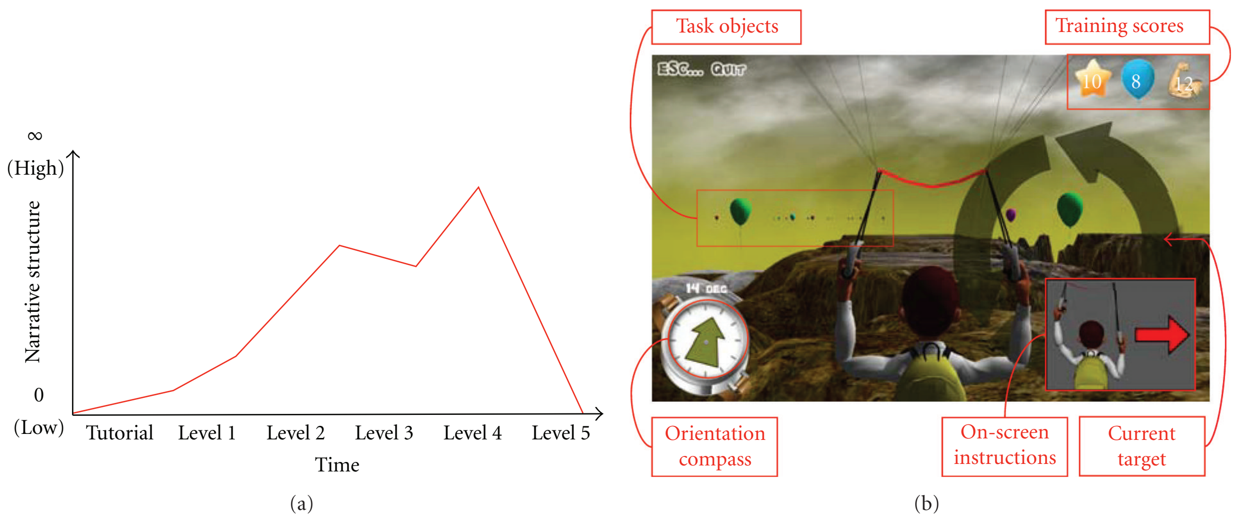

FIGURE 3: Game design elements of the Neurorehabilitation Training Toolkit (NTT). (a) Curve describing the narrative structure of the NTT where the different game levels are assigned to a narrative (interest) value. (b) Snapshot of the NTT training scenario during a game play. Task and feedback elements are indicated.

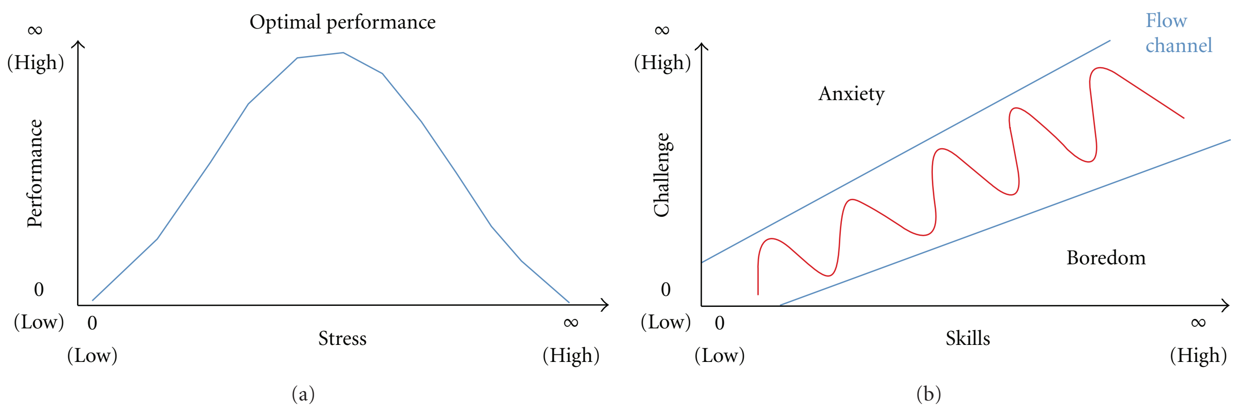

FIGURE 4: Design principles of the personalization of training with the NTT. (a) Yerkes-Dodson law established an inverted U-curve dependence between stress level and task performance. (b) Flow theory places the maximum user engagement in the balance between skills and challenge in a given task, described as the flow channel. See text for further details.

is continuously computed and updated on a screen counter (Figure 3(b)).

2.1.4. Personalization of Training. Since 1908, when Yerkes and Dodson discovered the relation between induced stress and task-learning performance in mice, it became clear that optimal learning is only achieved at intermediate stress levels [63]. Low and high levels of stress result in low performance levels (Figure 4(a)). These results were later replicated with humans in different research domains [64, 65]. Therefore, training systems such as the NTT that aim at optimizing motor learning and performance would benefit from incorporating this concept. Furthermore, the Yerkes-Dodson law is consistent with Csikszentmihalyi's flow theory that describes flow as "a state of peak enjoyment, energetic focus, and creative concentration by people engaged in adult play" [66]. Flow theory describes user experience during play (anxiety, boredom, and flow) depending on the challenge experienced and skill required. Flow is placed at the right balance between user skills and level of challenge (Figure 4(b)). Therefore, the NTT requires a built-in capacity to adjust the training parameters to an intermediate difficulty level, to avoid stressful/boring configurations, maximize learning, and to maximize user engagement as described by flow theory.

Our training parameters can be easily modified given that the NTT training task is implemented as a computer-based VR training task. A total of 4 task-related parameters (independent variables) define the training specifics: **speed** (the forward flying speed of the avatar), **turning** (turning speed of the avatar described as gain in (1)), **acceptance radius** (how close one has to be to an object to collect it), and **distance** (distance between collectable items). Therefore, the overall objective of the personalization of these parameters is to allow the NTT to provide its users with a transparent, automated, autonomous, and unsupervised personalization of training. Consequently, this personalization of training allows the NTT to support both optimized training (Yerkes Dodson law) and better user engagement (Flow theory). Additionally, the training parameters can also serve the purpose of monitoring motor improvements over time. The main research objectives of this work are to analyze the interactions between game parameters, relate them to quantifiable training objectives such as range of motion, coordination or movement smoothness, and to propose a model to automate the parameter selection for optimal training.

2.1.5. Deployment and Built-In Protocol. The most novel and possibly the strongest aspect of a rehabilitation tool such as the NTT is that it is accessible for millions of patients, anywhere in the world. This poses many opportunities but also some challenges. The most important challenge is probably the lack of a direct control on the usage of the NTT. This means that aspects such as instruction, training duration and parameters, data collection (questionnaires and game data), and informed consents have to be dealt with directly and automatically from the NTT site and the application itself. Thus, the NTT web site guides the user through a simple step-by-step tutorial on how to execute the NTT applet. Additionally, a video tutorial has been created to explain the usage of the Neurorehabilitation Training Toolkit. Only after giving informed consent for participation in a research study, the NTT application itself is launched.

The use of NTT requires a working email address to receive an access password and questionnaires. Consistent with previous studies, the duration of the training is set to 20 minutes with a suggested training frequency of three times per week [18]. The patients' behavioral data are automatically collected by the NTT.

Two self-report questionnaires were designed to gather demographic data, assess user experience and self-assessed improvements. The questionnaire on user experience consists of 13 questions that are presented in the format of a 5-point Likert scale where patients report their level of agreement/disagreement with respect to a number of statements. Self-assessed improvements in ADLs are evaluated by means of the modified Barthel Index questionnaire [67]. Questionnaires are sent via email in session 1 (start of training), 6 (2 weeks), 12 (one month), and so on. Questionnaires are displayed as web pages, and user data is collected using Google forms technology (Google Inc., Mountain View, CA, USA).

2.2. Pilot Study

2.2.1. Purpose and Procedures. In order to study the NTT properties and to develop a model for the automated update of the game parameters, a number of experiments were performed. 10 right-handed healthy naive participants aged 23 to 45 years ($M = 30.5, SD = 6.69$) from the University of Madeira were recruited to use the NTT. All participants were using the NTT for their first time, and the experiments were performed in a laboratory setting that always used the same hardware configuration. This pilot study followed standard approved guidelines and conformed to current EU and Portuguese legislation. All users gave their informed consent to participate in this study. Two identical mice (ems069i00, e-blue, Hong Kong) were used for tracking purposes. A total of 120 minutes of data were collected where participants played several "training levels" with random values for the different game parameters described in Section 2.1.4 (speed, turning, acceptance radius, and distance). These parameters were selected within the exploratory space described in Table 1, which was defined to range from an easy and controllable task to a difficult and highly demanding psychomotor task.

Table 1: Exploratory parameter space used in the NTT pilot-testing phase.

	Minimum	Maximum
Speed (flying speed)	4 m/s	80 m/s
Turning (turning speed)	15 deg/s	80 deg/s
Acceptance radius	1 m	10 m
Distance (between targets)	10 m	40 m

Complete log files of all game events, parameters, and all motor actions performed by participants were collected. These log files were stored in text format and subsequently imported into Matlab 2008a (MathWorks Inc., Natick, MA, USA) to perform the data analyses.

2.2.2. Accuracy of the Capturing Devices. Computer mice are inertial sensors, devices that are only capable of measuring instantaneous changes in position as opposed to absolute position. As a consequence, their position is calculated as the accumulated instantaneous changes in position, what makes them subject to drift. In order to assess the extent and impact of their drift, we have quantified it using AnTS, a camera-based vision tracking system that provides an absolute coordinate system free of drift (http://neurorehabilitation.m-iti.org/software/) [32, 68]. The AnTS tracking system was set up to track the position of the mouse on the table top while performing a NTT training session. The data from AnTS, captured using a camera with 640 × 480 pixel resolution and with a position accuracy of about 1 mm, was recorded synchronously with the reading from the mice. After the NTT session, we quantified the percentage of drift by comparing the position reconstructed with the mouse data and that coming from AnTS, it corresponded to 0.56% of the total distance travelled.

2.2.3. Kinematic Analysis of Upper-Limb Function. Relevant kinematic parameters for post-stroke rehabilitation include smoothness of movement, range of motion, and total arm displacement [60]. There is evidence showing that nonparetic arm kinematics and kinetics of patients do not significantly differ from those of normal subjects [69]. Thus, bilateral measurements from paretic and nonparetic arms become extremely valuable to assess and monitor improvement over time. Further, the NTT training task is unique because it allows us to assess characteristics such as arm coordination and contribution of each arm. Thus, data gathered by the NTT could allow for a kinematic analysis of upper-limb function, providing comparative data on each patient's paretic versus nonparetic arm. We performed a first pilot evaluation with healthy participants to assess the adequacy and validity of the NTT as a tool to assess the above-mentioned kinematic measures in healthy users.

Smoothness Index. Consistent with previous research, we define a Smoothness Index (SI) that quantifies the regularity and smoothness of a particular movement trajectory [69]. This measure allows us to assess the level of fine movement control of the NTT users for each arm independently. The smoothness of a movement depends on the number of segments in which it can be divided. Here we consider movement segments as those segments in between movement accelerations and decelerations. Therefore, the SI is computed from an analysis of the speed profile of a movement. We define SI as the count of the number of local minima in the speed profile for a specific action. Thus, lower SI values indicate movements with a smoother velocity profile, whereas higher values indicate those movements with more accelerations changes. Before the calculation of the SI, mice data are prefiltered with a Gaussian window filter of 1 sec length to reduce the amount of noise.

Arm Displacement. In order to display feedback about the actual work that has been realized, NTT also computes the accumulated distance that each hand has been displaced during training (Figure 3, training scores). This is a measure of actual physical exercise and allows us to assess the exact amount of physical movement that was needed by each user to complete the training tasks.

Range of Motion. Another relevant kinematic measure, related to the actual amount of physical movement, is Range of Motion (ROM). There is evidence that suggests that ROM can be used as a predictor of functional outcome in ADL [70]. As such, being able to automatically assess and monitor ROM throughout the training process can become a rather valuable feature of the NTT, particularly when complemented with the Barthel Index assessment for performance in ADLs [67]. The ROM that is measured by the NTT results from the combined action of shoulder and elbow (extension and flexion) on the end effector, the hand, which is tracked with the mouse. ROM captures aspects of the movement dynamics, providing information on functional arm aperture that other measures cannot provide. In the case of stroke patients, a limited ROM does not necessarily indicate limited movement within the working ROM. Our operational measure of functional ROM—the ROM being effectively used during the NTT training—is computed in cm from consecutive arm extensions and flexions as measured by mice.

Arm Coordination and Arm Contribution. As opposed to other rehabilitation approaches, NTT allows for an automated and objective quantification of functional outcomes, some of which are not possible to quantify in real-world tasks without the aid of interactive technologies. One particular example of this unique capability of the NTT is the ability to quantify arm coordination. During NTT training, and because of the bilateral nature of its training, physical movements are expected to be symmetrical movements performed simultaneously with both arms. We therefore quantify arm coordination as the absolute value of the correlation coefficient between the data from both mice. Consequently, the computation of the correlation coefficient of perfectly coordinated movements would result in a coefficient equal to 1. Our quantification of movement coordination is particularly advantageous for our purpose since the correlation operation is insensitive to the actual gain of the movement. Namely, perfectly correlated (coordinated) movements are not required to be of the same amount but should follow the same temporal profile. This means that the NTT enables us to separately assess movement coordination and arm contribution to the training task. The later—separate arm contribution—is computed by assessing the particular involvement of each arm in the steering of the avatar. Since the avatar's heading direction is driven by the differential in position of the two mice, the training can be performed with dissimilar involvement of the paretic and nonparetic arms (Figure 2). Thus, the contribution of each arm is computed as the correlation coefficient between the arm movement trajectories over time and the effective heading direction changes as described by (1). So, a low correlation coefficient will be obtained for an arm with reduced contribution to the bilateral control task.

Modeling. If successful, the ability of the NTT to provide us with relevant behavioral information about the patient's motor capabilities will allow us to assess the impact of the NTT on different aspects of motor recovery. Here we introduce how the NTT can be tailored to automatically self-adapt depending on the user's needs. In order to do so, we first have to quantify the relationship between our kinematic analysis of upper-limb function and the NTT training parameters. For that reason we use a multiple regression modeling approach. Consistent with previous work on psychometrics, our model considers all game parameters, its second-order terms, and first-order interactions [32]. In our case, we propose to model each of the previously described kinematic measures (Section 2.2.3) in the following way:

$$\begin{aligned}\textbf{Kinematic measure} = {} & c_0 + c_1 * \textbf{speed} + c_2 * \textbf{turning} \\ & + c_3 * \textbf{acceptance} + c_4 * \textbf{distance} \\ & + c_5 * \textbf{speed} * \textbf{turning} \\ & + c_6 * \textbf{speed} * \textbf{acceptance} \\ & + c_7 * \textbf{speed} * \textbf{distance} \\ & + c_8 * \textbf{turning} * \textbf{acceptance} \\ & + c_9 * \textbf{turning} * \textbf{distance}\end{aligned}$$

$$+ c_{10} * \textbf{distance} * \textbf{acceptance}$$
$$+ c_{11} * \textbf{speed}^2 + c_{12} * \textbf{turning}^2$$
$$+ c_{13} * \textbf{acceptance}^2 + c_{14} * \textbf{distance}^2, \tag{2}$$

where **kinematic measure** is the dependent variable (either movement smoothness, range of motion, arm displacement, or arm coordination); speed, turning, acceptance, and distance are the independent variables set by the NTT during our pilot-testing experiment, and the c_i constants are the coefficients resulting from the multiple regression analysis.

Besides the kinematic modeling approach, a parallel system is established to maximize challenge and engagement and therefore potentiate the highest performance level and flow. This is achieved by means of a time race [62, 71] during which NTT monitors the efficiency of the patient's actions by assessing his/her performance at every task completion (item collection) (Figure 5, efficiency assessment). Given that the flight speed and item distance are known training parameters to the NTT, it is possible to define efficiency in the following way:

$$\text{Efficiency} = \frac{\text{actual task completion time}}{\text{ideal task completion time}}. \tag{3}$$

Efficiency is computed at every task completion/object collection, which enables estimating how much time is needed by the patient on each task. Thus, the time race is implemented by providing every object with a timer that indicates how much time is left to collect it. The timer is based on the patient's efficiency data from previously collected items, being modulated by a Gaussian noise function (M = 1, SD = 0.2) (Figure 5, task time). Targets that allow more than the average time needed by the patient are presented as balloons (easy), and targets requiring less time are presented as stars (difficult). If the task is not completed within the time window, the target disappears and the timer is reset to a longer time as determined by the patient's mean efficiency (3). On one hand, this time race strategy allows personalizing the challenge of the task to the particular skills of the patient [62]. This design allows us to change task difficulty without interfering with the training parameters, which in our case determine the training objectives. On the other hand, training parameters (speed, turning, acceptance, and distance) are only updated when the patient's efficiency increases or decreases (3). Hence, the more efficient the patient is on the task, the higher the demands in terms of training objectives. Consequently, our personalization algorithm consists of two parallel loops that shape challenge and training parameters to provide optimized and enjoyable training.

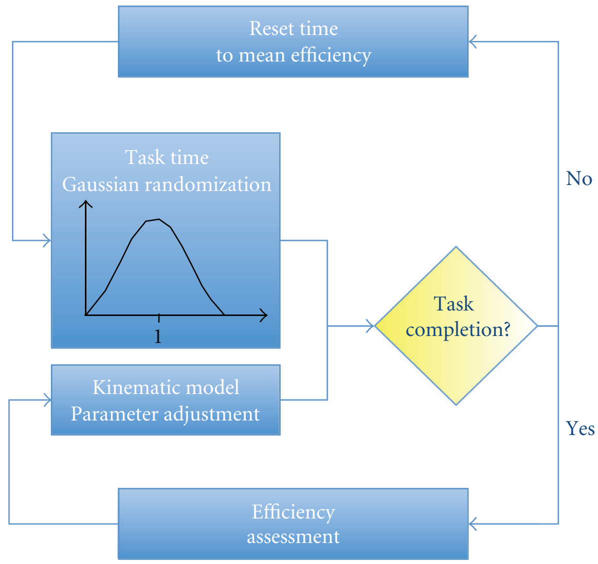

Figure 5: NTT personalization process. The adaptation of the training parameters is realized according to the patient's efficiency in the task. A kinematic model maps training objectives to individual NTT parameters. In parallel, a timer is used to create a time-race task. See text for further information.

3. Results

As described above, the NTT was evaluated with 10 right-handed healthy naive participants. As expected, healthy participants present a low Smoothness Index SI (MD = 5), with no significant difference between dominant and nondominant arms (Wilcoxon signed-ranks test, $Z = -.0212, P = .9831$) (Figure 6). A similar SI interquartile range (IQR) for dominant and nondominant arms is found (6.5 and 6, resp.).

Example data on arm displacement from participant number 1 is shown in Figure 7. A group analysis shows a median hand displacement of 23.25 cm per item collected, moving the dominant arm significantly less than the nondominant arm (Wilcoxon Signed-ranks test, $Z = 13.5642, P < .0001$).

Consistent with the arm displacement data, a paired sample t-test analysis revealed that the dominant arm uses a lower functional ROM (M = 23.38, SD = 16.14 cm) than the nondominant arm for healthy participants (M = 27.18, SD = 18.12 cm), $t(403) = -4.6924, P < .0001$ (Figure 8).

The investigation of arm coordination in healthy participants reveals a high degree of coordination, that is, high correlation values between the movement trajectories of the arms during the training task (M = .8143, SD = .2433). This is consistent with the high degree of motor control of this population of users (Figure 9). Interestingly, the arm contribution analysis of the NTT training task—which assesses the impact of the movement of each arm in the steering of the avatar—reveals larger contributions ($t(9) = -8.5925, P < .0001$) for dominant arms (M = .5631, SD = .1872) than for nondominant arms (M = .5095, SD = .2333) (see Section 2.2.3 for the details on the quantification of arm coordination and contribution). While this result is consistent with what is expected from dominant arms, in previous measures, we observed lower displacement and ROM for the dominant arm. This indicates that the dominant arm does not only contribute more, but it is also

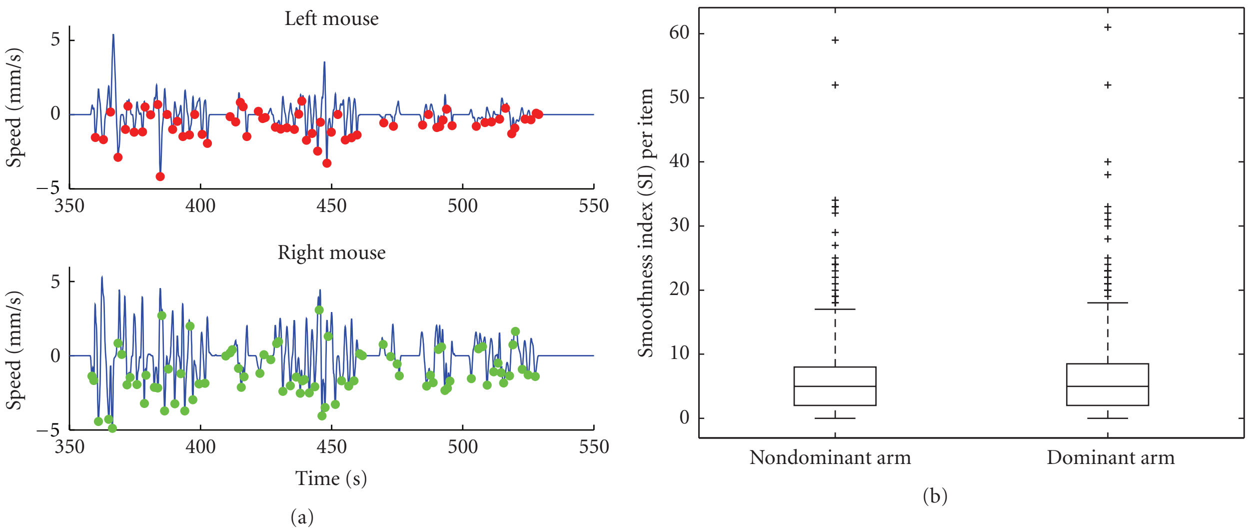

Figure 6: Analysis of movement smoothness by means of the Smoothness Index (SI). (a) Sample speed profiles of the movements tracked by both NTT mice. The number of movement segments contained in a specific movement trajectory is computed by locating the speed local minima (red and green dots). (b) SI is computed for each arm and for each item collected in the virtual training environment. Boxplot from 10 healthy participants. For more information see text.

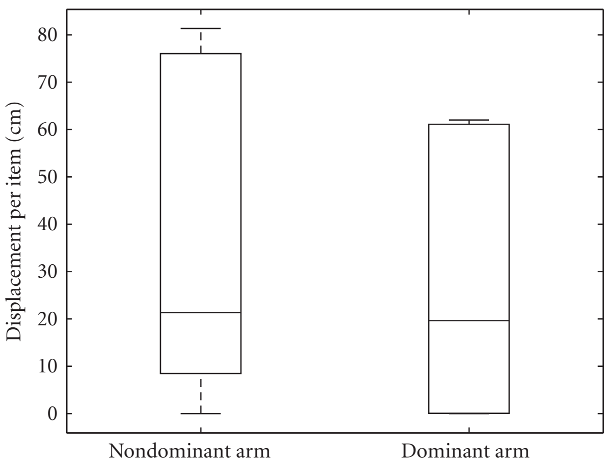

Figure 7: Arm displacement on the tabletop (cm) per item collected during a NTT training session. Data from healthy participant number 1.

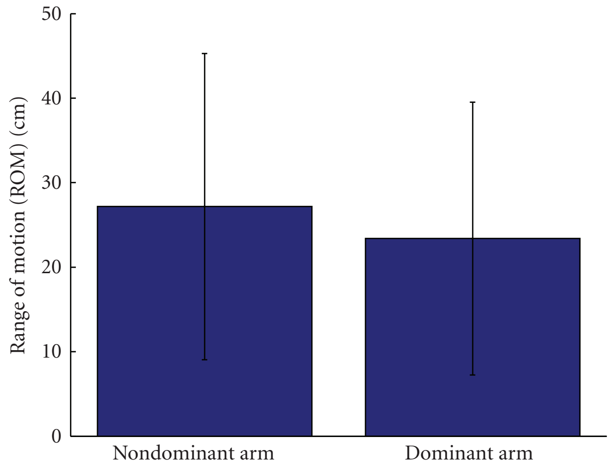

Figure 8: Range of Motion (ROM) usage during NTT training. Data consist of 404 data samples from the 10 healthy participants. Bar indicates mean ROM and error bars SD.

more precise in its actions, requiring less movement and ROM to accomplish the task.

Figure 9 shows that the NTT is capable of assessing different aspects of the movement kinematics when used by healthy users. Consequently, if we can assess how the NTT training parameters relate to the actual resulting physical exercise and movement kinematics on the tabletop, we can optimize the NTT training parameters accordingly to deliver appropriate and personalized training. Subsequently, we used these quantitative data on movement kinematics combined with modeling techniques to establish statistical relationships between the training parameters used and the actual physical exercise associated with them. We performed four separate multiple regression analyses to find out how the NTT training parameters contribute to the changes observed in the previously determined kinematic measures. Using the data from our healthy participants, we have identified the training parameters, the first-order interactions, and the second-order parameters that contribute to the movement smoothness, range of motion, arm displacement, and arm coordination (Table 2). The exact model coefficients described in (2) and related statistics are shown in Table 3 (see supplementary material available online at doi:10.1155/2012/802157).

From the multiple regression analysis we can conclude that not all training parameters contribute to all movement kinematics. This means that, depending on our training

Table 2: Table of significances of the multiple regression analyses. Crosses indicate terms that have a significant contribution to the kinematic measure and thus are taken into account in our modeling purposes. s, t, a, and d refer to the training variables flying speed, turning speed, acceptance radius, and distance, respectively. See Table 3 for further details on the model coefficients and related statistics.

	s	t	a	d	$s*t$	$s*a$	$s*d$	$t*a$	$t*d$	$a*d$	s^2	t^2	a^2	d^2
Movement smoothness				×										×
Range of motion		×				×					×	×	×	
Arm displacement										×				
Arm coordination					×	×								×

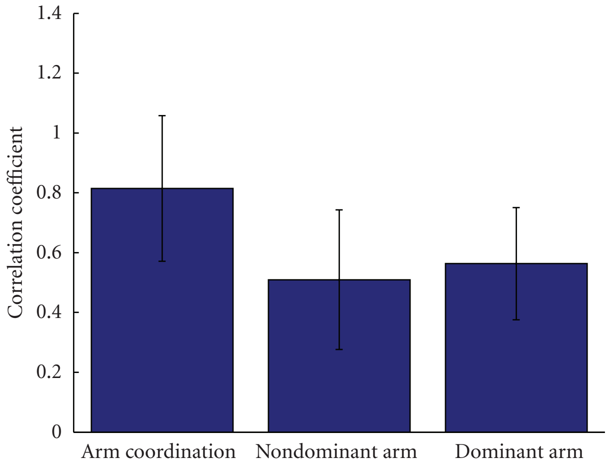

Figure 9: Arm coordination and contribution analysis for the NTT training task. Data from 10 healthy participants. Bars indicate the mean and error bars the SD.

objectives, a different set of parameters need to be changed to affect the user's movement kinematics. Thus, according to the relations established in Table 2, we have implemented a personalization training algorithm that can adjust the training parameters depending on the training objectives set by the user (Figure 5). In this algorithm for the adaptation of training, only a subset of the training parameters will be adjusted during training depending on whether the user needs to train movement smoothness, ROM, arm displacement, arm coordination, or any combination of these. The selection of the training objectives will therefore determine the kinematic models to be used during an NTT session (Figure 5, kinematic model).

4. Conclusions and Discussion

In this paper we presented the Neurorehabilitation Training Toolkit (NTT), a low-cost neurorehabilitation system that aims at offering an alternative for continued at-home rehabilitation after stroke. The NTT is designed along neuroscientific guidelines as well as game design principles to drive motor recovery, while maximizing engagement and motivational factors. Additionally, it is designed to be compatible with any modern PC that runs Windows O.S. and has an Internet connection. Because of its architecture and design, the NTT is a unique rehabilitation system. By capitalizing on broadly available home technology, the NTT is a free rehabilitation tool that is accessible worldwide via a web browser. This feature makes it immediately available for large-scale deployment, having an enormous potential as a motor training solution for patients in remote areas, with low income, low mobility, or without access to rehabilitation facilities. Furthermore, it is designed to serve as an at-home complement to other training or simply for continued rehabilitation after hospital discharge. Since NTT is accessed via a web browser, it does not have to be installed on the patient's computer and it is easily upgradeable, allowing patients to increase their portfolio of training games. NTT is a completely self-contained training system that does not require the intervention of a therapist or specialist. Further, NTT is a safe system completely based on noninvasive technologies, making it a suitable solution for unsupervised and at-home use. Based on the psychometric analysis presented here, the NTT is designed to automatically adjust its training parameters to the training. More concretely, NTT allows training movement smoothness, range of motion, arm displacement, arm coordination, or any combination of these based on the presented kinematic models.

As opposed to other approaches using technologies such as robotic devices, custom-made tracking technologies, brain-computer interfaces, data gloves, or expensive commercial hardware [16, 32, 51, 72–75], the NTT only requires a PC, a pair of computer mice and an Internet connection. This advantage of the NTT, which lowers the accessibility threshold for at-home rehabilitation training technologies, also represents one of its most important challenges. For instance, the lack of a supervised setting and the absence of complete upper-body tracking represent a limitation that more sophisticated systems do not suffer [16, 18, 75–77]. More specifically, the NTT kinematic analyses are based on the end effector. However, despite this caveat, the NTT is able to contribute with a detailed and functional analysis of training task performance. As reported in this paper, outcomes such as ROM, arm displacement, arm coordination, and individual arm contribution to the task objectives are unique assessment properties of the NTT. Our study with healthy participants has shown a precise quantification of ROM, coordination, arm contribution, and smoothness of movement, while also being able to detect handedness. Interestingly, the data revealed differences in ROM and arm contribution as result of handedness but no differences in movement smoothness. Compared to the nondominant arm, the dominant arm displayed a significant reduction of ROM while simultaneously showing an increased contribution in task performance. In the particular case of patients, ROM and accumulated displacement are expected to be more informative since they reveal different aspects of movement kinematics (arm aperture and amount of movement), which are not necessarily dependent. Although we have shown a high accuracy assessing functional outcome in healthy users, more research is needed to understand the limitations of this system when used by elderly and stroke patients. Given the nature of the bilateral training task and the possibility of supporting the actions of the paretic arm with the nonparetic arm, the use of compensatory movements is expected to be reduced. Nevertheless, we need to understand the extent of the use of compensatory movements and its effect in the assessed movement kinematics, since combined trunk, shoulder and elbow movements can contribute to effective hand movements. Similarly, the presented kinematic models generated with healthy user data need to be further validated in a trial with patients.

Despite the limitations of the presented psychometric modeling, the NTT goes beyond the adaptive and personalized training of previous work, allowing for a novel individualized and parametric training of several functional outcomes [18]. Finally, the automatic data-collection capability of the NTT and its questionnaire system enable a large-scale deployment to quantify its impact. We believe that rehabilitation technologies will continue to move in this direction, from custom and more expensive hardware-based solutions to low-cost systems that can be used at the patient's home [15, 16, 31]. The presented study is the first step that validates the design and technological aspects of the NTT with healthy users. In the next phase, it will be deployed and validated with stroke patients at their homes. The NTT, with its novel design principles and assessment capabilities, represents another step towards consolidation and at-home deployment of these technologies.

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Research Article

ENGAGE: Guided Activity-Based Gaming in Neurorehabilitation after Stroke: A Pilot Study

Ann Reinthal,[1] Kathy Szirony,[2] Cindy Clark,[3] Jeffrey Swiers,[1] Michelle Kellicker,[1,3] and Susan Linder[1,4]

[1] *School of Health Sciences, Cleveland State University, 2121 Euclid Avenue, Cleveland, OH 44115, USA*
[2] *Rehabilitation and Sports Therapy, Cleveland Clinic, 9500 Euclid Avenue, Cleveland, OH 44195, USA*
[3] *Rehabilitation and Sports Therapy, Lakewood Hospital, 14519 Detroit Road, Lakewood, OH 44107, USA*
[4] *Department of Biomedical Engineering, Cleveland Clinic, 9500 Euclid Avenue, Cleveland, OH 44195, USA*

Correspondence should be addressed to Ann Reinthal, a.karas@csuohio.edu

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Introduction. Stroke is a leading cause of disability in healthy adults. The purpose of this pilot study was to assess the feasibility and outcomes of a novel video gaming repetitive practice paradigm, (ENGAGE) enhanced neurorehabilitation: guided activity-based gaming exercise. *Methods*. Sixteen individuals at least three months after stroke served as participants. All participants received concurrent outpatient therapy or took part in a stroke exercise class and completed at least 500 minutes of gaming. Primary baseline and posttest outcome measures included the Wolf motor function test (WMFT) and the Fugl-Meyer assessment (FMA). ENGAGE uses a game selection algorithm providing focused, graded activity-based repetitive practice that is highly individualized and directed. The Wilcoxon signed ranks test was used to determine statistical significance. *Results*. There were improvements in the WMFT ($P = 0.003$) and the FMA ($P = 0.002$) that exceeded established values of minimal clinically important difference. *Conclusions*. ENGAGE was feasible and an effective adjunct to concurrent therapy after stroke.

1. Introduction

Stroke is one of the leading causes of disability in the United States with approximately 795,000 people experiencing stroke each year [1]. Many of these individuals are left with residual upper extremity deficits that limit independence with activities of daily living [2] and have been correlated with decreased self-reported quality of life [3]. Current research suggests that task-specific practice results in more functional improvement than traditional neuromuscular rehabilitation (TNR) [4–6]. TNR after stroke has been defined as a typical contemporary practice that includes a combination of active, impairment-based exercises, functional task practice, passive exercise, and activities to enhance sensory inputs [2, 7]. However, based on an observational study by Lang and colleagues [7], only 25% of a typical 36-minute upper extremity therapy session involved functional task practice. While the number of practice repetitions required in task-specific practice is not yet fully delineated, it is thought that individuals after stroke must practice for a minimum of several thousand repetitions in order to relearn a task [5].

Several obstacles exist to obtaining adequate practice. First, there are a large number of tasks to be practiced, and while there is some transfer of learning between similar tasks, such as picking up a coffee mug and a can of soda, practicing these tasks would not necessarily be helpful for learning to write with a pencil [5]. Second, repetitive practice of a single task may be boring both to the patient and the clinician [7–10]. Third, the learner must actively engage in task practice; it is not adequate to be passively moved through the motion or activity [7, 11]. Finally, to ensure optimal movement quality and therapeutic benefit during task practice, a skilled professional must often supervise [8–10], making it expensive to provide the necessary hours of training.

Current approaches that provide the opportunity for repetitive practice include constraint-induced therapy (CIT), robotics, and virtual reality (VR). In CIT, the individual is *forced* to practice various tasks repetitively with the hemiparetic arm for six hours a day in a structured environment and for 90% of waking hours, while the nonhemiplegic arm is constrained. Successful candidates for CIT have higher functioning hands, with some active control of wrist and finger extension [6, 12]. Both the minimal movement requirement and the intensive structured therapy protocol preclude many patients after stroke from benefiting from this intervention. Robotic instrumentation actively guides movement during repetitive practice, providing partial assistance while also constraining the movement to occur in a specific "correct" movement pattern. These devices have been successfully utilized in people after stroke with both high- and low-level functioning upper extremities primarily in research environments [13, 14], but have not been widely adopted in traditional clinical settings. Finally, VR environments provide a three-dimensional computer-generated immersion experience where the "player" completes the task similarly to doing so in the real world. The experience is typically engaging, realistic and has been shown to transfer to a comparable real world activity. VR has been successfully used after stroke and can provide upper extremity repetitive task practice to both lower and higher functioning upper extremities [15, 16], but its scalability has been limited due to both size and expense of the equipment requirements.

Video gaming systems such as the Wii and PlayStation II with Eye Toy are commercially available, inexpensive virtual reality-type systems that have been used as an effective adjunct to TNR for individuals with stroke [8–10, 17, 18]. Gaming provides an engaging interaction which is critical in optimizing motor learning [5] and can be easily tailored to individuals with varying degrees of paresis, similarly to some robotic and VR systems, but unlike CIT interventions that are only appropriate for higher functioning arms. Three mechanisms are hypothesized to account for the effectiveness of video gaming in inducing neuroplasticity. First, gaming frequently utilizes more energy than sedentary activities [19] which is important since individuals after stroke are typically less active [20], and enhanced cardiovascular fitness has been shown to improve cortical plasticity [21, 22]. Second, gaming offers significant bilateral practice opportunities, hypothesized to effectively induce reorganization in contralesional motor networks [23–28]. Finally, during play, the gamer sees an avatar concurrently performing the activity on screen providing visual biofeedback [18, 29], similar to techniques using the mirror neuron network after stroke [30, 31]. This network involves the activation of neurons in the parietal and premotor cortex during actual movement and when observing others moving [32].

For this study, we developed a novel method of integrating commercially available video gaming into TNR after stroke called ENGAGE, enhanced neurorehabilitation: guided activity-based gaming exercise. The aims of this study were to (1) examine the *feasibility* of adding ENGAGE as an adjunct to TNR in a natural clinical practice environment without additional skilled therapy personnel costs using commercially available gaming equipment; (2) examine whether practice completed through ENGAGE gaming leads to *improvement in upper extremity function* in individuals after stroke; (3) examine effects of covariates on the efficacy of ENGAGE gaming, including concurrent rehabilitation, quantity of gaming time, initial motor and sensory function, and chronicity after stroke; (4) examine whether study participants found gaming to be *motivating* as compared to home exercise program practice.

2. Methods

2.1. Study Design. The study was approved by the Institutional Review Boards for Human Subjects Research at the Cleveland Clinic and Cleveland State University, and informed consent was obtained from each participant. Each participant consented to participating in this study. This study utilized a mixed-methods design, with qualitative measures used to address *aim no. 1: feasibility* and *aim no. 3: covariate analyses*. A within-subject pretest posttest design, consistent with the principles of community based participatory research [33] was used to address *aim no. 2: improvement in upper extremity function* and *aim no. 4: motivation*. Outcomes were assessed without a control group, evaluating practice in a natural clinical practice environment. Two sites within a regional health system were utilized, representing urban and suburban clinical settings.

2.2. Participants. Patients enrolled in outpatient physical and/or occupational therapy or those participating in a community-based stroke exercise class were eligible to participate. In this pilot study, there was no attempt to control what occurred in concurrent outpatient physical and/or occupational therapy, but activities were consistent with contemporary practice as described by Lang et al. [7] and Miller et al. [2], and included adjuncts such as functional electrical stimulation. Participants in the exercise class completed cardiovascular exercises in addition to basic group stretching and strengthening activities. Inclusion criteria included the following: (1) hemiparesis in the involved upper extremity between Brunnstrom stages 2–6; (2) ≥three months after stroke; (3) sufficient balance to sit safely in unsupported sitting while participating in video gaming; (4) adequate cognitive and communication skills to learn video game within three sessions; (5) the ability to play independently or with support staff assist after set up. Participants were excluded if they had confounding medical interventions during the course of the study, such as upper extremity botox injections. A convenience sample of the 16 participants who completed a minimum of 500 minutes of gaming was included in the outcomes analysis. For this pilot investigation, a minimum of 500 minutes of gaming time was chosen based on the expectation that 12–16 sessions of outpatient rehabilitation is typical before significant improvement occurs, and that each session typically includes a mean of 36 minutes of actual activity [7], resulting in 432–576 minutes of practice. Participant demographics are summarized in Table 1.

2.3. Outcomes. Baseline and posttesting were completed using the upper extremity portion of the Fugl-Meyer

Table 1: Participant demographics.

Gender	8 males; 8 females
Side of hemiparesis	10 right; 6 left
Age (years)	63 ± 13.9 (38–86)
Chronicity (months)	26 ± 25 (3–77) (5 subacute; 11 chronic*)
Exercise class or outpatient therapy	6 exercise class**; 10 outpatient therapy
Gaming time (minutes)	1089 ± 619 (594–2816)
Concurrent occupational therapy	7

*Subacute 3–9 months after stroke; chronic >9 months after stroke.
**All exercise class members chronic.

assessment and the Wolf motor function test as the primary outcome measures in this pilot investigation. Secondary clinical outcome measures included portions of the stroke impact scale and intrinsic motivation inventory. Detailed training and administration manuals were developed and used by all evaluators for the FMA and WMFT. During posttesting, evaluators were blinded to baseline results.

2.3.1. Fugl-Meyer Assessment [34]. The upper extremity motor portion of the Fugl-Meyer assessment (FMA) is a 33-item test that assesses reflex integrity and active movement. The FMA is measured on an ordinal scale from 0–2 (0 = cannot perform, 1 = performs partially, 2 = performs flawlessly) with a maximum possible score of 66. A study by Lin et al. determined that the FMA has high concurrent validity with $P = 0.82$–0.96 [35], high interrater reliability (ICC = 0.96), and high test-retest reliability (ICC = 0.99) [36]. The minimal clinically important difference (MCID) for the upper extremity portion of the FMA is 6.6 points, or 10% of the total score of 66 [37]. An additional section of the FMA assesses upper extremity sensation, with two items for light touch and 4 items for proprioception. This section uses the same 0–2 point ordinal scale for a total of 12 points for normal sensation [34].

2.3.2. Wolf Motor Function Test [38]. The timed tasks of the Wolf motor function test (WMFT) include 15 items that assess gross and fine motor tasks. Psychometric properties have been established, with an interrater reliability of $r = 0.97$ ($P < 0.05$) and an internal consistency of 92.4% [38]. Lin and colleagues have determined the MCID to be 1.5 to 2 seconds in subacute stroke [39].

2.3.3. Stroke Impact Scale [40]. The stroke impact scale version 3.0 (SIS) is a self-reported quality of life measure that includes 59 questions over eight domains (strength, hand function, activities of daily living (ADL), mobility, communication, emotion, memory and thinking, and participation). The SIS utilizes a 5-point scale where the person rates the difficulty of each item. For this pilot investigation, the ADL (no. 5) and hand function (no. 7) subsections were chosen as most reflective of change expected as a result of the intervention. Lin and colleagues established MCID levels for the ADL and hand function subscales at 5.9 and 17.8 points, respectively [41].

2.3.4. Intrinsic Motivation Inventory [42]. The interest/enjoyment subscale of the intrinsic motivation inventory (IMI) is a self-report measure consisting of seven items. Each item is rated on a scale of 1 to 7 according to how true the statement is for the participant. The IMI was used at posttesting, to compare interest/enjoyment in gaming relative to a home exercise program. Validity has been established for this measure [42].

2.4. Intervention. ENGAGE can be distinguished from standard video gaming in the following ways. First, it uses a game selection algorithm that provides focused, carefully graded activity-based repetitive practice of cognitive-perceptual-motor tasks. It offers highly individualized and directed exercise in the form of playing video games in order to specifically address the unique constellation of each individual's neurological impairments after stroke. Second, it uses a limited number of gaming system platforms and games. Third, it is guided by the neuromuscular rehabilitation clinician, yet carried out under the direct supervision of support personnel or, in this study, students, thereby reducing cost while maintaining the intensity and quality of practice. All clinicians who participated as coinvestigators were experienced neurorehabilitation specialists (17–32 years of experience each).

2.4.1. Game Selection Algorithm. A game selection algorithm was developed and used in this pilot study. The first step involved determining the specific and unique needs of each individual after stroke. After completion of an initial examination/evaluation by the clinician, the participant and clinician developed a realistic collaborative functional goal, an important factor in obtaining an engaged commitment to practice [36, 43, 44]. Next, the clinician completed functional task analysis of the goal in conjunction with an assessment of current impairments of body structure/function such as limitations in strength, passive range of motion (PROM), motor control, and sensation that might limit that function/activity. Limiting motor components such as decreased antigravity shoulder flexion were prioritized, as well as critical and interacting nonmotor impairments, such as diminished ability to attend or hemineglect. Games were then selected to bridge the gap between the patient's impairments and the movement required to complete the functional goal. The algorithm allowed for *preparatory work on impairments and task components* before moving on to practice the actual task, but the gaming itself was always part of a *meaningful* activity.

In order to efficiently select the appropriate game for a given participant, games utilized in the study were analyzed using a taxonomy representing multiple continua of motor skill difficulty [45] with tables developed to identify these motor components for each game. The first set of factors relating to the environmental demands of playing the game identified whether the environment was stationary (i.e., golfing) or in motion (i.e., batting), and if successful play required force modulation and/or accuracy (i.e., archery). The second set of factors involving the body's interaction with the task demands determined which upper extremity joints needed to move in what planes of motion in relation to gravity (i.e., antigravity shoulder flexion with elbow extension during bowling), whether the task needed specific types of grasp and hand/finger manipulation (i.e., drumming versus playing the guitar), if the task itself was continuous (i.e., boxing) or discrete (i.e., golf swing), and whether it required unilateral or bimanual dexterity (i.e., tennis versus canoeing). The ability to complete bimanual task training was another important feature considered in this model, since bimanual function is variable, utilized in more than 54% of hand activities [46], and has been shown to be an efficacious rehabilitation tool [23, 24, 26–28]. Bimanual skills were further subdivided into four categories: bimanual assisted (i.e., two-handed activity such as golfing with hemiplegic hand ace wrapped to controller); yoked (i.e., baseball batting); reciprocal (i.e., driving); differing (i.e., playing the guitar). In addition to a game's specific upper extremity motor demands, other critical nonmotor factors were considered. For example, cognitive demands were matched with the patient's ability to understand and learn the game. Associated cardiovascular demands were assessed; in general, continuous tasks (i.e., boxing) that require the player to perform a movement without rest had higher demands than games composed of discrete tasks (i.e., bowling) where there is rest between repetitions. Other nonmotor domains included sensation/perception and trunk control/balance. Changes in these nonmotor areas were not specifically monitored outside of the sensory section of the FMA.

2.4.2. Gaming System Platforms and Games. Therapists' knowledge of the different game options was essential for appropriate game selection. While an adequate number of games was necessary to meet the varied needs of the different individuals post stroke, this was balanced by the need to know the various game features and requirements. Therefore, games were chosen from six different discs using one of two gaming system platforms, the Sony PlayStation II with EyeToy (games: Play 1, Play 2, and Rock Band) or the Nintendo Wii (games: Wii Sports, Wii Resort, and Wii Play), providing a wide array of options with varying degrees/types of difficulty. The Wii controller contains accelerometers that are actuated by multiplanar tilting, rotation, and acceleration movements, as well as through various control buttons. The EyeToy is a motion-sensitive USB camera that utilizes visual biofeedback by projecting a real time image of the player onto the TV screen. Players see themselves moving within a virtual environment that is superimposed on an image of the actual background [9]. The EyeToy provides more options for individuals with lower functioning arms and/or more cognitive deficits because it is not necessary to activate the accelerometer-based hand controller or manage button controls. Numerous modifications and props were developed to make games more task specific, graded for difficulty, and individualized for the heterogeneous population (i.e., enlarging the wheel during driving, covering unused buttons on the Wii controller). Figure 1 shows an individual playing the game Bubblepop on the PlayStation II with EyeToy, utilizing a precision pinch grasp while holding a pen to pop the bubbles on the screen.

Figure 1: Playing Bubblepop on the PlayStation II with EyeToy.

2.4.3. Delegation to Support Personnel. After completing the above analysis, the treating clinician used a goal recording form as a communication tool for the students completing the intervention with all participants. This form listed the collaborative goal, precautions, the primary motor and secondary nonmotor goals, and a list of possible games addressing these goals along with any required modifications. The assisting students were health sciences undergraduate, graduate, and doctor of physical therapy students. The students were required to know how to use each gaming system and play all the games. Training manuals were developed for this purpose and to serve as a quick reference for trouble shooting during gaming sessions. The supervising clinician was always present during gaming, but was treating other patients. Standardized intervention recording logs were used to track what games were played, how much time was spent playing each game, and modifications to the game.

3. Analysis

The Wilcoxon signed ranks test was used to calculate differences in the Fugl-Meyer assessment, Wolf motor function test, stroke impact scale, and intrinsic motivation inventory. Data were analyzed using SPSS Version 18 statistical software package. MCIDs were compared to group means for the FMA, WMFT, and SIS (MCID not available for IMI). In addition, for this pilot study, the following covariates were examined: (1) initial level of arm/hand function, as measured by the initial FMA score, (2) time after stroke (subacute versus chronic), (3) concurrent TNR, (4) the amount of gaming time, and (5) sensation.

4. Results

4.1. Feasibility. The algorithm developed for game selection based on individualized goals and deficits as presented in

Table 2: Summary of pilot study outcomes.

	FMA UE bafore	FMA UE after	WMFT before	WMFT after	SIS no. 5 ADL before	SIS no. 5 ADL after	SIS no. 7 hand before	SIS no. 7 hand post
Mean	39/66	47/66	41 sec.	30 sec.	62%	64%	33%	38%
SD	20	20	39	39	20	18	25	25
P value*		0.002*		0.003*		0.551		0.599

*Statically significant $P < 0.05$ with the Wilcoxon signed-ranks test.

Section 2 was feasible. In a given gaming session run by undergraduate and graduate students, the clinician spent an average of 10 minutes giving instructions and assisting with game selection and modification. Overall, the commercially available game options met the needs of a wide range of deficits after stroke and were highly modifiable. However, it was important that the supervising clinician as well as the students was knowledgeable about the different gaming options. About 50% of the participants needed some hands on assistance from the students during the gaming sessions.

4.2. Improvement in Upper Extremity Function. Table 2 summarizes the means and standard deviations of the outcome measures. The average score on the FMA increased by 8 points ($P = 0.002$), which is greater than the 6.6-point MCID [37]. The mean improvement of 11 seconds on the WMFT ($P = 0.003$) was greater than the 1.5- to 2-second MCID in subacute stroke [39]. There was no statistically significant difference in the two subscales of interest in the SIS : ADL ($P = 0.551$) and hand function ($P = 0.599$).

4.3. Covariate Analysis. Several analyses were completed with the primary outcome measures, the FMA and WMFT, to help delineate inclusion criteria for the planned randomized clinical trial (RCT). First, FMA and WMFT results were examined in relation to initial arm function as measured by the FMA scores (Figure 2). As a result of this analysis and in conjunction with research on return of arm function after stroke [47, 48], participants were grouped into four groups. Participants who had initial scores of 10 and lower (no. 1 and 2) did not benefit from the intervention, while most individuals in the other three groups (11–35; 36–55; 56–66) did improve.

In order to determine whether time after stroke affected outcomes, participants were grouped into either subacute (3–9 mo post) or chronic (>9 mo post) categories [3] based on when they began the gaming study. Figure 3 shows that while the subacute group made larger gains, the chronic group also improved.

The effect of concurrent upper extremity traditional neuromuscular rehabilitation was examined. All participants were either receiving concurrent occupational therapy (OT) consisting of traditional upper extremity neuromuscular rehabilitation, outpatient physical therapy which focused primarily on the lower extremity neurorehabilitation, balance, and/or aerobic training, or were participating in an exercise class. As seen in Figure 4, while both groups improved, those individuals receiving concurrent upper extremity traditional neuromuscular rehabilitation had greater improvements.

Since the amount of gaming time was self-selected in this pilot project, its affect on the outcomes was examined. Participants were grouped according to minutes of gaming time as follows: 500–999 minutes (56% of participants), 1000–1499 minutes (25% of participants), and 1500 minutes or more (19% of participants). As can be seen in Figure 5, the group who completed the greatest amount of gaming showed the greatest improvement. No significant difference was found between the low and middle gaming time groups.

Finally, Figure 6 illustrates the changes seen in participants presenting with initial sensory dysfunction on the FMA. All but one of the 11 participants showed improvements in sensation at the time of postintervention testing.

4.4. Motivation. Motivation to practice was assessed using the IMI. This was statistically significant ($P = 0.001$ using the Wilcoxon signed-ranks test) with the mean increasing from 5.3/7 (sd = 1.0) for the home exercise program to 6.4/7 (sd = 0.7) for gaming.

5. Discussion

In this pilot study, we found that participants were highly engaged in the gaming activities, resulting in improved participation in this voluntary adjunctive intervention. This, in turn, led to the completion of significant quantities of repetitive goal-directed practice at levels rarely obtained in traditional outpatient upper extremity neurorehabilitation [7]. The virtual reality literature discusses the concept of "presence" as a form of positive, active engagement that occurs during the VR experience [49]. Our observations are consistent with work by Rand and colleagues [9] who noted a high sense of presence during gaming for their participants.

It was feasible to use the ENGAGE protocol to provide large quantities of meaningful and engaging practice in a realistic clinical environment. While not formally measured throughout the study, actual practice repetitions varied from only a few per minute for games like golf and bowling to over 50 repetitions per minute in games such as boxing and drumming. The game selection algorithm allowed for preparatory work on impairments and task components as part of a meaningful activity before progressing to practicing the actual task. This may clarify the recent discussion about the effectiveness of upper extremity task practice [50–53], since we hypothesize that an underappreciated critical component is meaningful and engaged practice rather than

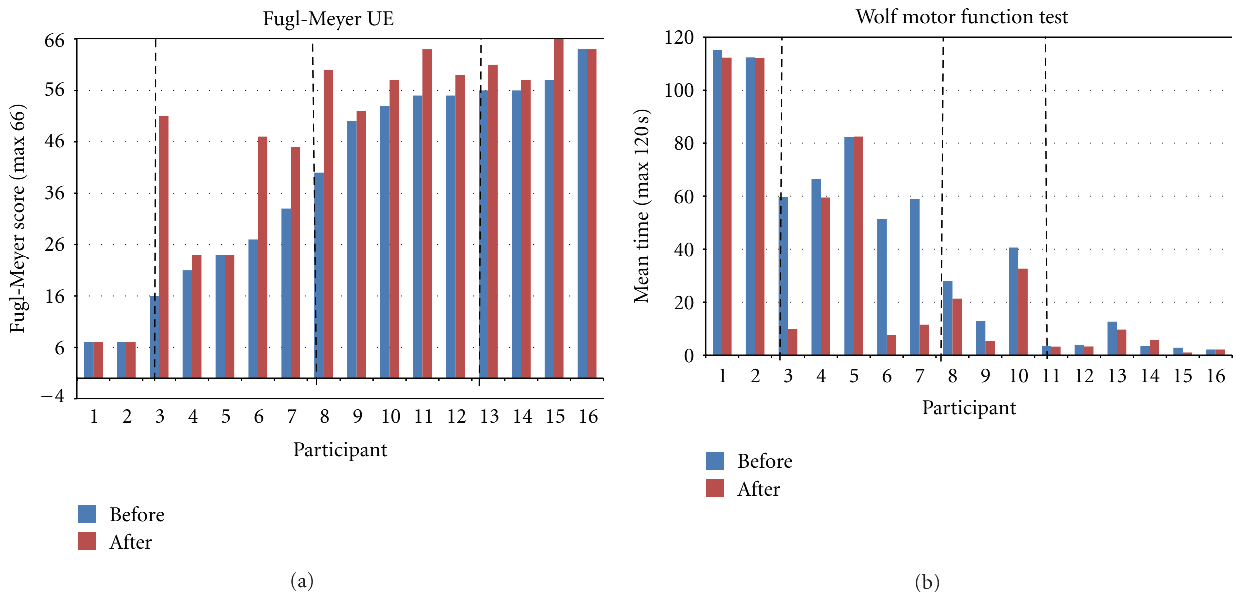

Figure 2: Motor outcomes based on initial UE function on FMA.

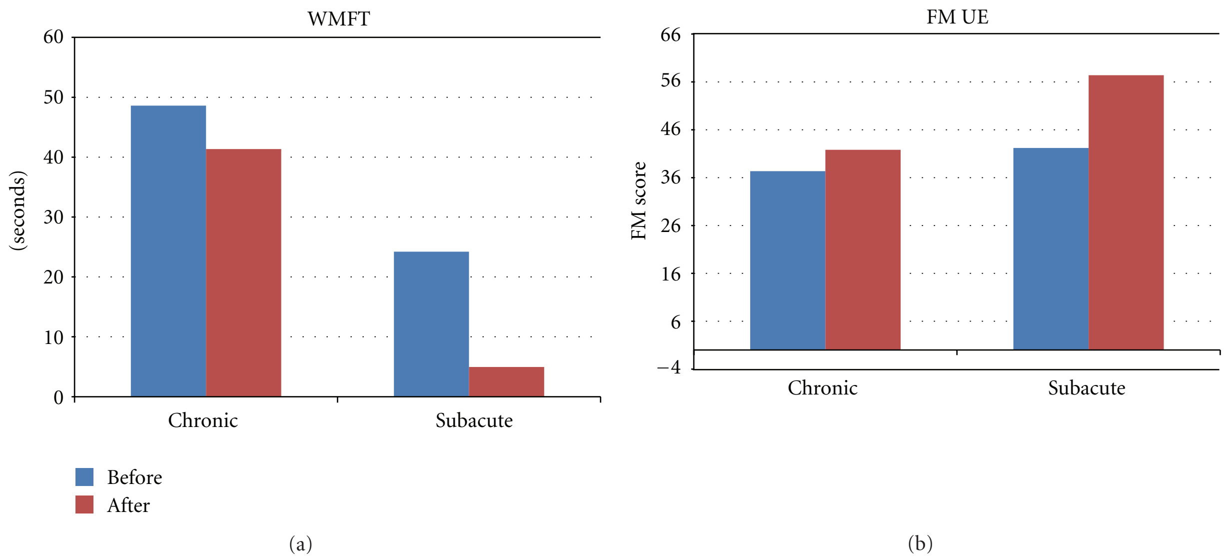

Figure 3: Effect of time after stroke on motor outcomes.

just task specificity. Of additional importance in this small pilot sample is the fact that this intervention resulted in significant changes in motor function for individuals with lower functioning upper extremities (initial FMA upper extremity scores between 11–35) in addition to those with higher function, including some hand and wrist movement. These lower functioning individuals would not be candidates for CIT [6]. At present, the primary evidence-based approaches for these individuals are robotics and virtual reality interventions which are typically expensive and not universally available to the clinical community [14, 15, 54]. The ENGAGE protocol, however, uses inexpensive, commercially available video gaming equipment in a clinically feasible protocol. In our upcoming randomized clinical trial, we plan to include individuals with upper extremity FMA scores of >10 at three months or more after stroke since those with lower motor function did not appear to benefit from the protocol. It is probable that some baseline level of motor function is necessary to actively participate in the gaming intervention. In addition, the single very high functioning individual (initial FMA score of 64/66) did not improve on our motor outcome measures. Therefore, we plan to exclude individuals with FMA scores >63 because few of the games require high levels of dexterity practice to sufficiently challenge such an individual.

Coordinating gaming with simultaneous upper extremity neuromuscular rehabilitation improved outcomes in this pilot study. Thus, our upcoming trial using the ENGAGE

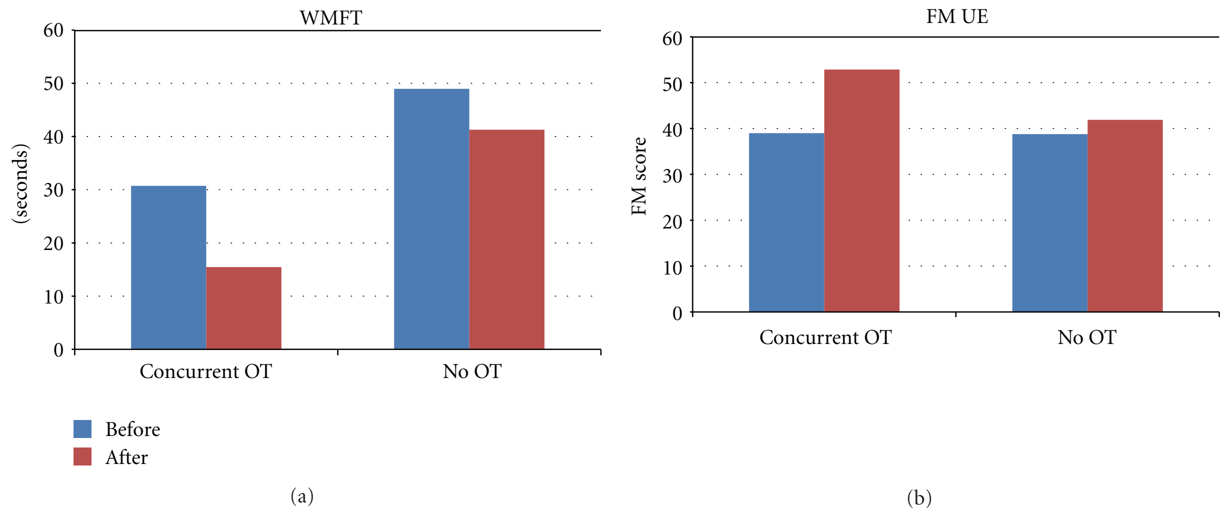

FIGURE 4: Effect of concurrent upper extremity traditional neuromuscular rehabilitation (OT) on motor outcomes.

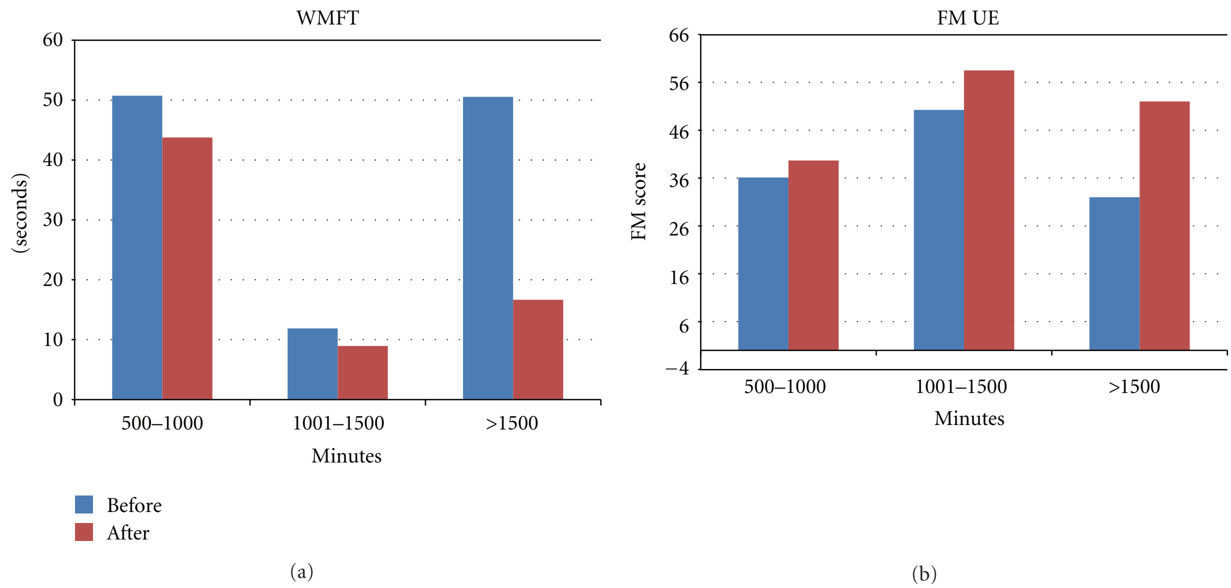

FIGURE 5: Effect of gaming time on motor outcomes.

protocol will include two intervention arms, each with a different percentage of concurrent upper extremity rehabilitation, to better quantify the dosage of skilled versus adjunctive therapy necessary to result in clinically significant changes in motor function. It offers a novel way to use gaming to substantially increase repetitive practice opportunities at a reduced cost compared to conventional practice [7], while remaining highly individualized and targeted.

The ENGAGE protocol was found to be a cost-effective intervention, due in large part to the ability to utilize students and support staff. In addition to the time required to train clinicians and staff, expense of equipment must be considered. We were able to use only two different gaming system platforms, the Wii and PlayStation II, along with six different game discs on the two systems. This provided a wide selection of gaming options, allowing us to meet the needs of individuals at various levels of arm function, to provide variability of practice opportunities, and to prevent the boredom that often occurs when completing one task repetitively. While it was critical for treating clinicians to be familiar with all game options, limiting game selections meant that busy clinicians could learn the different game alternatives in a reasonable amount of time.

Our data analysis revealed several unexpected results. First, we measured upper extremity sensation using the FMA as a potential covariate. We found that 11 out of the 12 participants with sensory loss improved on this section of the FMA postgaming. While we know that sensory function is a critical component in motor learning [55], there is little consensus in our research literature about interventions

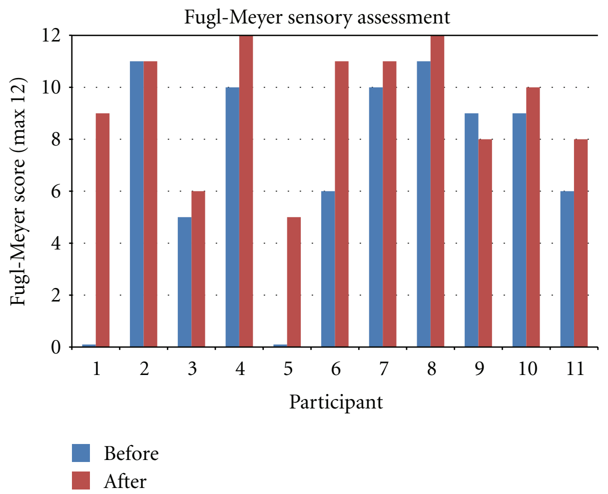

Figure 6: Changes in FM sensory assessment for participants presenting with initial dysfunction.

to improve sensation after stroke [56]. These preliminary results warrant more systematic evaluation of sensory function in our upcoming trial. Second, we hypothesized that the subacute group would improve significantly more than the chronic group. Although this pattern did emerge, the difference was small, supporting the theory that many individuals after stroke with upper extremity dysfunction learn not to use the hemiplegic arm and hand [57] and that at present, we do not provide adequate interventions in this area [7]. Based on these pilot results, we will continue to enroll individuals with both subacute and chronic stroke since both groups demonstrated clinically significant levels of change. In this convenience sample representative of the outpatient population of the two participating facilities, half of the outpatient participants were at least six months after stroke. Finally, the one area where participants did not change was the SIS, which is a reflection of the participant's perception of their function, rather than an actual measure of function [40]. Examining the results of only the subacute group, we measured changes beyond the MCID of 5.9 in the ADL subsection (increased from 58.5 to 71), but not beyond the MCID of 17.8 for the hand subsection (increased from 42 to 44) [41]. This can be explained by the fact that several of these individuals did not regain functional use of the hemiplegic hand. Also, it is hypothesized that individuals in the subacute group may have become more aware of the degree of deficit over time after discharge home. The lack of change in the chronic group is potentially a reflection of a more stable perception in their function during the longer time since the stroke event.

This study has a number of limitations. As a pilot clinical outcomes study, there was no control group and no control for concurrent therapy. Additionally, the amount of gaming time was self-selected by each individual participant. These factors will be controlled in our upcoming trial. Dosage questions are unanswered by this study, especially since the 500–999-minute and 1000–1499-minute practice groups made similar gains. The use of gaming time rather than actual practice repetitions may account for this finding, since there is a large variation in repetitions between slow-paced games such as golf and bowling and fast-paced games such as boxing and sword fighting. An accelerometer-based system has been designed as part of this pilot study and will be used in our upcoming trial to quantify the amount of practice required for clinically relevant and functional change [58]. Based on these preliminary data, the protocol for our upcoming trial has been designed to include two intervention arms examining a dosage of one additional hour of gaming for each of twelve weeks, as compared to an hour of TNR. This will provide a total of 720 additional minutes of gaming time or TNR in conjunction with two weekly sessions of TNR. A power analysis has been completed on these preliminary data for this noninferiority hypothesis. A followup testing session one month after completion of the gaming intervention will also be included.

Second, although all raters were trained and used the detailed administration manual developed for the FMA and WMFT, there were multiple evaluators during this study, and interrater reliability was not specifically assessed. The protocol for our upcoming trial includes a blinded evaluator who has been standardized in the administration of the outcome measures to complete all baseline and postintervention testing.

Third, postural stability was not formally assessed in this investigation although improvements were observed that were potentially aided by the gaming intervention. These observations warrant a more systematic evaluation of postural stability in the planned subsequent RCT.

Finally, more objective measures of engagement are needed, as a ceiling effect might have occurred with the IMI. Anecdotally, we, as a group of experienced clinicians, rarely observed a level of engagement in traditional neurologic rehabilitation as witnessed during gaming. We feel the IMI results may have been confounded by the socialization that occurred during gaming but not during home exercise.

6. Conclusion

In this pilot investigation, we found that the use of ENGAGE protocol was feasible in a clinical environment. There was a statistically significant improvement in upper extremity function as measured by the upper extremity portion of the FMA and by the WMFT, and participants were motivated to use this gaming protocol. Dosage of gaming time remains unclear, but individuals who completed at least 500 minutes of the intervention demonstrated improvements in function. In future work, the ENGAGE protocol will be used as an adjunct to concurrent upper extremity rehabilitation.

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Research Article

Motor Imagery Experiences and Use: Asking Patients after Stroke Where, When, What, Why, and How They Use Imagery: A Qualitative Investigation

Corina Schuster,[1,2] Andrea Glässel,[3,4] Anne Scheidhauer,[1] Thierry Ettlin,[1,5] and Jenny Butler[2]

[1] *Research Department Reha Rheinfelden, Salinenstrasse 98, 4310 Rheinfelden, Switzerland*
[2] *Department of Sport and Health Sceinces, Faculty of Health and Life Sciences, Oxford Brookes University, Oxford OX3 0BP, UK*
[3] *Institute of Health and Rehabilitation Sciences, Ludwig-Maximilians-University Munich, 80539 Munich, Germany*
[4] *Faculty of Social Work and Health, University of Applied Sciences and Arts, 31134 Hildesheim, Germany*
[5] *Department of Behavioural Neurology, Medical faculty, University of Basel, 4053 Basel, Switzerland*

Correspondence should be addressed to Corina Schuster, c.schuster@reha-rhf.ch

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Background. A framework on where, when, what, why, and how to use imagery from sports psychology was explored whether it can be applied in patients after stroke in their chronic stage. *Methods*. Eleven patients (ages 31–85, 3 females, 1.3–6.4 years after stroke) were interviewed. Semistructured interviews were conducted before and after a two-week MI intervention period with six MI sessions. Information was obtained regarding experiences and knowledge of MI, and the evaluation of an MI practical example. The coding scheme was based on the framework and a hierarchical categorisation. *Results*. Information regarding domains where, when, what, why, and how to use imagery was addressed. Patients imagined themselves as healthy individuals, did not focus on surroundings during MI practice,and reported to use positive imagery only. After MI training, patients became more flexible regarding their location and position during MI practice. *Conclusions*. MI became an automatic process, and patients did not need specific concentration and quietness as mentioned in the first interview. Patients recommended daily MI training and began to transfer MI to practice movements that were affected by the stroke. In contrast to sports, patients did not talk about how MI was triggered rather than how MI was designed.

1. Introduction

Motor imagery (MI) is a recognised and established method for different individuals (children, students, athletes, and patients) and for different purposes (cognitive, strength, and motor-related tasks). During recent years, MI has received increasing attention as a training approach in rehabilitation of stroke patients [1–4]. However, designing effective imagery interventions depends on patients' typical normal use, intentions, and imagery content when using the technique. Currently, patient experiences and meanings attributed to MI are widely unknown so far.

After adopting MI in stroke rehabilitation in the late 1990s, it has been shown to be beneficial for motor function recovery when added to physical practice [1, 2]. Decety and Grezes have defined MI as "...a dynamic state during which the representation of a given motor act is internally rehearsed within working memory without any overt motor output" [5]. Research has been performed investigating different techniques of MI and their effect on both motor function and psychological parameters [6–8].

In psychology, the influential work of Kosslyn et al. moved the research perspective from applying MI in interventions with individuals to research in the natural occurrences and use of MI in everyday life [9]. The authors asked twelve undergraduate student volunteers to keep an imagery diary for one week and note down when and where imagery had been used. Students had to describe the situation they were in when imagery occurred, the content of what has been imagined, and the vividness of the image. Furthermore, authors wanted to know why individuals had used imagery and what the intention to use imagery in the current situation was. Additionally, students had to define their understanding of a "mental image." Study results were analysed regarding the categories modality, purpose, and content of imagery. It could be shown that visual and auditory imagery modes were mostly reported. The category purpose included six types: more than half of the study population reported associative (e.g., day dreaming), problem solving (e.g., mental maps to navigate), mental practice (e.g., imagine swimming stroke), memory recall (e.g., imagine notes during test), comprehending descriptions (e.g., image based on verbal description), and emotional or motivational stimulus (e.g., to calm down), as imagery content coloured and concrete (vivid) images were the most frequent reported ones. In the same paper, they described a second study on imagery every day use that confirmed the findings of the first experiment for all three categories: modality, purpose, and content [9].

Ten years later, Munroe et al. used semistructured in-depth interviews in 14 athletes from various disciplines to find answers on where, when, whym and what imagery has been used. Obtained information had been structured according to these 4-Wquestions. In addition, information on why using imagery had been structured according to Paivio's framework on effects of imagery on human motor performance [10, 11]. In this framework, Paivio [11] suggested two main functions of imagery (cognitive, motivational) that work on a general level, for example, cognitive general and motivational general, or specific level, comprising cognitive specific and motivational specific types. Motivational functions are used to reduce anxiety or increase self-confidence. Cognitive functions, for example, attention, enable athletes to use different imagery perspectives and to transfer the imagine tasks to competitive situations. However, for the current investigation, it will be interesting if patients after stroke will address both aspects from their personal experience. In the patients' case, "competitive situations" could be related to movements, tasks, or settings that are challenging due to motor function limitations. Furthermore, Paivio's findings influenced Munroe et al.'s results classification for athletes imagery use: during and outside practice, for precompetition, competition, and postcompetition. Furthermore, their analysis on imagery content included type (visual, kinaesthetic) and perspective (internal, external) of MI.

In 2005, Nordin and Cumming interviewed 14 professional dancers to describe their imagery use [12]. Again, information was categorised according to the 4-W-questions: where, when, why, and what have been imagined. In their analysis, a new domain has emerged on how images were obtained. This domain included three categories: external stimuli, retrieving memories, and creating triggers.

Moving away from healthy students and athletes, Driediger et al. investigated athletes with musculoskeletal injuries and their use of imagery during the recovery process [13]. Ten athletes of various disciplines with different severity of injury had been interviewed once. Imagery was used for cognitive (e.g., learn rehabilitation exercise, motivational (e.g., goal setting) and healing reasons (e.g., distraction from pain)). Imagery was mainly performed during physiotherapy sessions prior to physical practice of an exercise. The authors described the content of athletes' imagery as vivid with both modes: visual and kinaesthetic, and with a positive performance. That included imagination of the athlete her/himself as a healthy individual performing in her/his sports discipline as successful as before the injury.

To create an international perspective of imagery use in supraelite athletes, MacIntyre and Moran interviewed twelve canoe-slalom competitors from Germany, Ireland, United States, and the United Kingdom [14]. Their purpose has been to investigate where, when, what, why, and how athletes use imagery. In addition, the authors were interested in the metacognitive control of imagery and asked athletes about their importance of imagery and why they have used this method. Results revealed different imagery directions (facilitative and debilitative) and strategies to overcome problems in activity sequences, for example, talk through a slalom course with the trainer.

So far, the existing framework on where, when, what, why, and how to use imagery from sports psychology has not been explored in brain-damaged individuals. The objective of this study was to investigate whether the imagery framework questions (where, when, what, why, and how) for MI can be applied in chronic-stage patients after stroke. The specific aims were (1) to evaluate whether the imagery framework questions (where, when, what, why, and how) established in mainly healthy and young students and athletes can be adopted by an older stroke population and (2) if new insights for the design of MI interventions can be obtained.

To address the aims mentioned above, a qualitative research method approach was used. This well-established research method originates from the social sciences. Obtained information from semistructured interviews, focus groups, or observations helps to understand and explore behavioural processes and generate hypotheses rather than testing experimental hypotheses. The participant's perspective and perceptions on unexplored concepts, diseases, or phenomena are the main focus of the investigation gathering textual information rather than numbers [15–18]. Applying semistructured interviews in the current investigation is most appropriate given the nature of the topic under investigation. In this approach, the interviewer could ask and explain the abstract construct of MI and giving the patients the opportunity to ask questions and check their correct understanding. The applied procedure offered the opportunity to acquire detailed information on the nature of patients' MI experiences, associations, MI training session elements (e.g., MI mode and state of eyes), and temporal parameters (e.g., duration of MI and number of MI trials).

2. Methodology

The goals of this work were approached using a framework-based qualitative research method, using semistructured interviews. Information reported in this paper, including reflexivity, study design, and data analysis, followed the qualitative research review guidelines (RATS) and the 32-item consolidated criteria list for reporting qualitative research (COREQ) [19, 20].

2.1. Study Design and Procedure. This qualitative investigation based on an explorative content analysis and was nested into a randomised control pilot trial (RCT) investigating two MI training approaches in patients after stroke. After giving written informed consent for the MI intervention trial, patients underwent two baseline measurement events, including MI ability assessments, balance evaluation, and assessment on independence of living. Following the baseline assessments, patients were randomised to one of three study groups. Patients allocated to either of the experimental groups (EG1, EG2) were asked whether they would like to participate in two semistructured interviews, one before and one after the two-week MI intervention period. Patients were informed about the procedure by the interviewer (CS) and received a second patient information sheet specifically developed for the interviews. The third group served as a control group. All three groups received standardised physiotherapy treatment focussing on balance. Patients MI training methods in EG1 and EG2 did not differ regarding content, duration, or frequency. The main difference can be seen in the integration approach of MI. One experimental group (EG1) embedded MI into physiotherapy. The second experimental group (EG2) added MI after the physiotherapy session. Patients of all groups had to practice one motor task physically "Going down, laying on the floor, and getting up again" in a standardised order. In EG1 and EG2, the motor task has also been practiced mentally. The control group listened to audio tapes with information related to stroke after physiotherapy. In total, treatment time was about 45 to 50 minutes for each group. A detailed study protocol is described elsewhere [21]. The study was implemented according to the Declaration of Helsinki and was approved by the ethics committee of the School of Health and Social Care of the Oxford Brookes University, Oxford (UK) and the responsible Swiss ethics committee (Aarau, Kanton Aargau, Switzerland, reference number 2008/077).

2.2. Interviewee Sampling and Data Saturation. Patients were recruited from both experimental groups (EG1, EG2) of the ongoing MI intervention trial with the following selection criteria: first ischemic or hemorrhagic stroke at least three months before study entry, being able to stand with or without a cane for at least 30 seconds on a normal hard floor, being able to walk 20 metres with or without a cane or an orthosis, older than 18 years, and score at least 20 in the Mini-Mental State Examination (MMSE), given written informed consent. Patients were excluded if they had joint replacements (knee, hip, and shoulder), movement-limiting pain in the upper or lower body evaluated with the 11-point visual analogue scale (VAS), limited range of motion in hip, knee, ankle joints, or toes, bodyweight exceeding 100 kg, or having a compromised mental capacity to give written informed consent. Further restrictions resulted from the patients' ability to communicate and express thoughts, experiences, and feelings. Patients with severe speaking problems were not included. During the recruitment period between April 2009 and May 2010, eleven out of 26 patients fulfilled the selection criteria and agreed to participate in the semistructured individual interviews. The MI intervention study, which was closely connected to the semistructured interviews, determined the bounds for data saturation in patient interviews of this work. Saturation refers to the point at which the investigator has obtained sufficient information from the field [22].

2.3. Interview Setting. Interviews were conducted face to face between the patients and the first author (CS). Following written informed consent, interviews were conducted one to two hours before the first of six MI intervention sessions. The second interview took place after the last MI intervention session. To provide a high level of privacy and to avoid disturbances, all interviews took place in a separate treatment room of the rehabilitation centre. Patients were offered refreshments during the interview. Furthermore, patients could decide to not answer a question and to have breaks at any time during the interviews, if they wished to do so. Interviews were recorded with two redundant digital voice recorders to avoid loss of data. Patients and interviewer did not know each other before oral and written study information was given. After the first interview, CS worked with the patients during all six MI intervention sessions, which could have had an influence on the patients' reporting during the second interview.

2.4. Interview Guide and Procedure. A generic interview guide was developed for the first interview to account for different symptoms after stroke, for example, paresis level and psychological capacity. The interview guide was developed based on the interview guide published by MacIntyre and was divided into three parts [14]. Bearing in mind that MI could be very abstract to patients, the first part of the interview was not related to MI, but focused on the stroke event, patients' rehabilitation process including therapy experiences, and occurrence of falls. In the second interview part, patients were asked about their previous experiences and knowledge of MI. In the third interview part, a practical example of MI was performed, which included a sit-to-stand task. After performing this task twice physically, it was twice mentally practiced and again twice physically practiced. The aims of the simple and quick to perform practical example were (1) to provide patients, regardless of their previous MI experience, with MI experience, which helped them to describe MI content elements, for example, used MI mode (kinaesthetic, visual), perspective (internal, external), and imagined environment, and (2) to control for actual MI performance by recording the time (sec) needed to perform the example mentally and practically. The guide for the second interview only included questions regarding patients' experiences with MI during the previous two interventions weeks and a repetition of the practical example. In the final phase of both interviews, patients were asked to evaluate the interview, including questions on whether it was exhausting and how they liked it. Furthermore, patients' answers were summarised by the interviewer as a means of member checking, and patients had the opportunity to comment on, add to, or omit statements. The interview guides are provided in Table 1.

Three pilot interviews were conducted to familiarise with the interview procedure, test the interview guide, and practice the technical setup. No changes to the interview guide were deemed necessary after the pilots.

During and after the interviews, field notes and an interview report were written by the interviewer to describe important aspects of the interview (e.g., patients' mood, unexpected disturbances) as well as patients' gestures and behaviours. If leading questions emerged during the interview situation, answers were not included in the analysis. To verify the patient "yes" or "no" answers, another question with the opposite meaning was offered to the patient.

2.5. Data Analysis, Credibility, and Trustworthiness Procedures. Figure 1 provides an overview on all methodical steps from data recording to final analysis. All recorded interviews were transcribed verbatim (computer text document) by AS. Two researchers (KL, AH) involved in the assessments of the related MI intervention study checked the transcripts for a second time. Afterwards, all transcripts were checked for a third time by CS and copied into computer spread sheets for further analysis [23]. All verbatim-transcribed interviews were mailed to the patients for verification. Five of all mailed patients gave feedback and agreed with the reproduction.

The questions where, when, what, why, and how to perform MI were not considered for developing the coding scheme in the first line. With this approach, all emerging themes from the raw data could be captured. To address the quality item credibility, CS and AG developed the coding scheme jointly, based on three interviews before MI intervention and three interviews after MI intervention. The scheme was extended during further interview coding by CS. Each patient phrase or sentence was coded, where one sentence could contain information mapped to more than one code. At maximum, one sentence or phrase was matched to five codes. After coding was completed for all interviews by CS, AG applied the final coding scheme to code the MI-related part of one interview. This peercheck conformed to code cross-checking and evaluated the established codes [18]. Coding agreement was 80% (84 of 105 phrases), which was obtained before a consensus discussion. If both researchers (AG, CS) had not been able to agree on a decision (which was not the case in this investigation), a third researcher (JB) would have been consulted. In the summary and analysis step, only information related to MI was used. Patients' information was then transferred into a matrix to provide an overview on all patient statements matching one code. Based on this matrix, data were interpreted and allocated to the domains, categories, and subcategories of a hierarchy tree (FreeMind, version 0.8.1). The imagery framework questions (where, when, what, why, and how) represented the highest analysis level. Category names were derived from MI training session elements extracted in a systematic literature review on MI techniques [24]. Further domains and categories were added to the hierarchy tree to represent the complete range of patient information. Codes used in the coding scheme and their allocation to the respective domain are listed in Table 2.

To further increase the rigour of the analysis, two methodological details need to be considered. Firstly, all patients underwent two baseline measurement events of the MI intervention trial. The assessments on MI ability performed during the baseline measurement events supported patients' knowledge and interpretation of the MI construct. Secondly, during the interviews' practical MI example (sit-to-stand and back), patients and interviewer had to record the time needed with a stopwatch. These measurements helped to ensure a basic understanding and knowledge on the interview topic of interest for all patients. Furthermore, the triangulation of patients' interview data and assessment data helped to gain a broader picture of patients' MI understanding, but also to limit misinterpretation of interview data [18]. In general, at no time during the analysis were data modified or made to fit with the considered imagery framework (where, when, what, why, and how questions).

3. Results

3.1. Patients and Interviews. Important patient characteristics are displayed in Table 3. During all interviews, only patient and interviewer were present, except during the first interview where the patient's wife was present too (Pat. 32). In total, 20 interviews were conducted. Nine patients were interviewed twice, and two patients were interviewed before the MI intervention only due to patients' time constraints. Once during the first interview (Pat. 32), both voice recorders did not work properly, and about one-third of the interview could not be recorded. The duration of the interviews was averaged 38.4 min for the first and 22.3 min for the second interview. Patients' responses produced 216 lines of text (average) during the first interview, with only half (average of 106 lines) related to MI. During the second interview, patients' responses produced 124 lines of text (average) with 107 lines (average) that were MI related.

3.2. General Data Analysis Results. Information contributing to the patients' statements was based on experiences and knowledge acquired before the study, the practical example of MI performed during the interview, and on assumptions patients made after exercising the MI example. Example quotes were translated from German into English by CS and were double-checked by KL, who is a German native speaker but has proficient level in the use of English. The first two levels (domains and categories) of the hierarchy tree used in the data analysis are displayed in Figure 2 and Table 2.

3.2.1. Where Using MI?

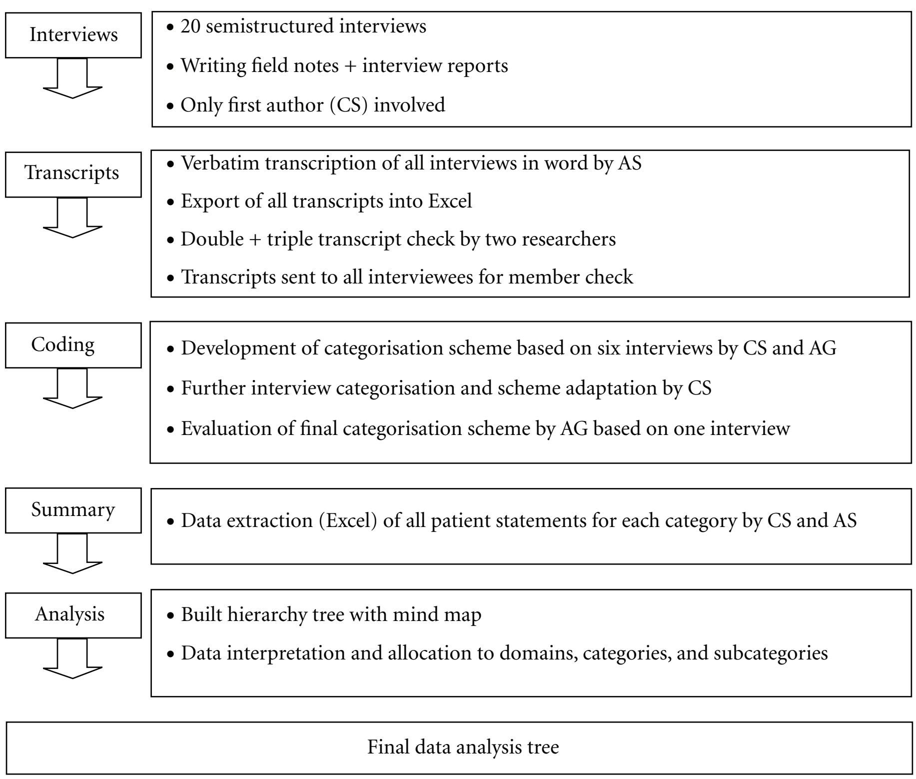
The domain WHERE comprises two categories: (a) *location* and (b) *position* of the individual during MI. Both categories could be related to preparation for MI practice and consist

Table 1: Interview guides.

Interview	Interview part	Interview questions
1st interview	The first focused on the stroke event, patients' rehabilitation process including therapy experiences and occurrence of falls.	When did your stroke occur? How did you recognize that you had a stroke? What symptoms did you have? How did you feel when the stroke happened? How do you feel today? How was your recovery process? What is your main problem at the moment? How do you feel when you are walking? Have you been falling since you had the stroke?
	The second interview part focussed on patients' previous experiences and knowledge of MI.	How does it feel to you to do motor imagery? What do you associate with motor imagery? (a) Did you know motor imagery before you have done the assessments? (b) How did you get to know about motor imagery? (c) When do you do motor imagery? (d) How do you do motor imagery? (e) What do you imagine? (f) What kind of experiences have you made with motor imagery?
	In the third interview part, a practical example of MI was performed, which included a sit-to-stand task. After performing this task twice physically, it was twice mentally practiced and again twice physically practiced. Patients were asked to describe the content of the MI example.	Was it easy to imagine the movement (standing up, sitting down)? If yes, why was it easy? If not, why was it not easy? What exactly have you imagined? How detailed was the movement? What kind of surroundings/environment have you imagined? What kind of perspective have you used (internal, external)? What comes to your mind if you remember the imagination of the movement? (a) What have you seen? (b) What have you felt? (c) What have you heard? (d) What have you smelled? Do you think that motor imagery could help patients after stroke during the recovery process? If yes, why? When and how often would you do motor imagery? Where would you do imagery? What expectations do you have regarding the MI intervention during the next weeks?
	In the final phase, patients were asked to evaluate the interview, including questions on whether it was exhausting and how they liked it. Patients had the opportunity to comment on, add to, or omit statements.	What do you think about the interview? Was the interview exhausting? How do you feel now after the interview? Would you like to add something?
2nd interview	The first part focused on questions regarding patients' experiences with MI during the previous two interventions weeks.	How did you like the motor imagery intervention? What do you think about motor imagery now? Do you think motor imagery can help during the recovery process after a stroke? How can motor imagery help during the recovery process? Would you use motor imagery in the future to learn or improve a motor task? (a) Why? (b) When-how often? (c) Where? (d) What?

Table 1: Continued.

Interview	Interview part	Interview questions
	In the second part, the practical example from the first interview was repeated. Afterwards, patients were asked to describe the content of the MI example.	Was it easy to imagine the movement?
		Why was it easy/not easy?
		What exactly have you imagined?
		How detailed was the movement?
		What kind of surroundings/environment have you imagined?
		What kind of perspective have you used?
		What comes to your mind if you remember the imagination of the movement?
		What have you seen?
		What have you felt?
		What have you heard?
		What have you smelled?
		Did you think that motor imagery helped you to improve the motor task?
	Final phase	Please see first interview



CS = Corina Schuster
AS = Anne Scheidhauer
AG = Andrea Glässel

Figure 1: Data conduction, preparation, and analysis process.

of three subcategories each. In relation to *location*, three patients (Pat. 19, Pat. 38, and Pat. 6) talked about their home (living room, basement, garage,and garden), and one patient also specified the brightness of the location as being necessary (Pat. 19). He explicitly denied practising in the basement. Another male patient (Pat. 37), who used imagery during his marathon preparation before stroke onset, explained that he could practice MI anywhere, for example, in the train. For him, it was not necessary to calm down, neither to have a focussing moment before MI

Table 2: Translated codes, categories, and domains for interview data analysis.

	English code	English category	English domain
	MI usage	Expectation MI intervention	
	MI example		
	MI example: grasp something		
	originating of MI		
	Preknowledge MI: yes—from sports		
	Preknowledge MI: yes—not from sports		
	Preknowledge MI: no		
	Practical performance motor task: grasp glass		
	Practical performance motor task: grasp something		
	Practical performance MI: to craft something		
	Practical performance motor task: toe and finger movements	Patients' prestudy knowledge of MI	
	Practical performance motor task: movements		
	Practical performance motor task: jogging training		
	Practical performance since stroke: no		
	Preexperience MI: from assessments		
Goals for intervention period (upcoming 2 weeks)	Preexperience MI: operating sequence		
	preexperience MI: yes		Patients' pre-study knowledge, experience, and understanding of imagery
	Preexperience MI: yes— sport		
	Preexperience MI: thought about MI		
	Preexperience MI: no		
	Preexperience MI: did not help		
	Preexperience MI: disappointment		
	Preexperience: content MI		
	Meaning of MI		
	Reasoning for MI usage		
	Performing MI		
	Belief in MI: negative		
	Belief in MI: positive	Patients' understanding of MI	
	Belief in MI: sceptical		
	Hypothesis on MI requirements		
	Personal belief in MI		
	Requirement MI: quietness		
	Preexperience: other psychological technique (e.g., psyching up, activity planning)		
	Preexperience: other psychological technique (e.g., psyching up, activity planning)		
	Preexperience: autogenetic training	Other prestudy mental imagery experiences	
	Preexperience: content autogenetic training		
	Preexperience: dreaming		
	Performing MI: saying to yourself		
	Preexperience: other psychological technique (e.g., psyching up, activity planning)		

Table 2: Continued.

	English code	English category	English domain
	Assumption MI intervention period: not helpful Assumption MI intervention period	Belief in MI after MI intervention regarding prestudy MI experiences	
MI content/reflecting on sit-to-stand example	Performing MI: location	Location	Where
	Starting position MI	Position	
	Assumption: starting position MI	Position	
	Assumption: location MI	Location	
	Performing MI: concentrating	Concentration	When
	Performing MI: concentrating no	Concentration	
	MI: concentration difficulties	Concentration	
	Duration MI	Duration	
	Performing MI: simultaneously with other activity	Situation	
	Assumption: time of the day	Time of the day	
	Reasoning for MI: MI content surroundings	Content MI of MI example	What
	Assumption: MI content	Content of MI during MI example	
	MI content: stand up	Content of MI example	
	MI content: motor task incomplete	Movement completeness	
	MI content: motor task complete	Movement completeness	
	MI content: motor task unclear	Movement completeness	
	MI content: motor task like healthy people	Content of MI example	
	MI content: imagine always the same	Content of MI example	
	MI content: walking	Content of MI example	
	MI content: person	Content of MI example	
	MI content: see yourself	Content of MI on MI example	
	MI content: sensation yes	Senses	
	MI content: sensation no	Senses	
	MI content: sit-to-stand	Content of MI on MI example	
	MI content: sit-to-stand (SS) complete	Movement completeness	
	MI content: SS surroundings	Content of MI example	
	MI content: imagine always the same	Content of MI example	
	MI content: walking	Content of MI example	
	MI content: person	Content of MI example	
	MI content: see yourself	Content of MI on MI example	
	MI content: sensation yes	Senses	
	MI content: sensation no	Senses	
	MI content: sit-to-stand	Content of MI on MI example	
	MI content: sit-to-stand (SS) complete	Movement completeness	
	MI content: SS surroundings	Content of MI example	
	MI content: SS surroundings unclear	Content of MI example	
	MI content: SS unclear	Content of MI example	
	MI content: surroundings	Content of MI example	
	MI content: surroundings light	Content of MI example	
	MI content: surroundings nothing	Content of MI example	

Table 2: Continued.

	English code	English category	English domain
	MI content: independent from surroundings	Content of MI example	
	Combination with physical practice	Concentration	
	Transferring MI to different people: unclear if MI is helpful	Concentration	Why
	Continuing MI: yes	Motivation of post-study MI usage	
	Continuing MI: no	Motivation of post-study MI usage	
	Continuing MI: unclear	Motivation of post-study MI usage	
	Eyes open during MI	Eyes	
	Eyes closed during MI	Eyes	
	Assumption: MI_slow motion	Speed	
	Reasoning for MI: speed	Speed	
	Reasoning for MI: closed eyes	Eyes	
	Reasoning for MI: order	Order MI and physical practice	
	Performing MI: concentration phase before MI	Components	
	Performing MI: find quietness before MI	Components	
	Performing MI: speed	Speed	
	Performing MI: eyes closed	Eyes	
	Performing MI: perspective	Perspective	
	Performing MI: order MI versus physical practice	Order MI and physical practice	How
	Assumption: duration MI	Duration	
	Assumption: effect repetitions	Number of MI trials per MI training session	
	Assumption: speed MI	Speed	
	Assumption: order MI versus physical practice	Order	
	Assumption: less time for sit-to-stand example mental	Speed	
	Assumption: repetitions MI	Number of MI trials per MI training session	
	Kinaesthetic	Mode	
	MI content: MI speed normal	Speed	
	MI content: feel movement yes	Mode	
	MI content: feel movement no	Mode	
	MI content: feel movement unclear	Mode	
	MI content. SS perspective external	Perspective	
	MI content: SS perspective internal	Perspective	
	MI content: SS perspective unclear	Perspective	
	MI repetitions	Number of MI trials	
	Reasoning for MI: usage		
	Reasoning for MI: simple		
	Reasoning for MI: helpful		
	Reasoning: sceptical versus MI		
	Reasoning for MI: difficult	Patients' understanding of MI	
	Reasoning for MI: not helpful		Post-MI intervention considerations
	Performing MI: simple		
	Performing MI: difficult		
	Reasoning for MI: not difficult		
	Reasoning for MI: continuing	Patient's MI intervention evaluation	
	Learning effect regarding MI intervention		

Table 2: Continued.

	English code	English category	English domain
	Learning effect regarding MI intervention: new movement sequence		
	Learning MI		
	Transferring MI to different movement sequence: general	Patients' learning effect due to MI intervention	
	Transferring MI to different movement sequence: walking		
	Transferring MI to different movement sequence: fingers/hand		
	Transferring MI to different movement sequence: no		
	Transferring MI to different movement sequence: difficult		
	MI content: get up from the floor		
	Transferring MI to different people: MI is helpful	MI attributes/qualities	
	Transferring MI to different people: MI is not helpful		

Table 3: Patient study characteristics.

Int. number	Patient number	Age	Gender	Stroke	Affected brain area	Time since stroke (yrs)	MMSE	EBI	BBS	KVIQ vis. 1st inter.	KVIQ kin. 1st int.	Lines of text 1st int.	Lines of text 2nd int.	Duration in min 1st int.	Duration in min 2nd int.
1	6	61	Female	CVI	Right	1.3	28	62	43	48	48	234 (102)	163 (147)	39.1	23.4
2	**13**	53	Male	CVI	Left	1.7	27	62	55	29	27	251 (130)	141 (116)	44.3	23.3
3	15	31	Female	ICB	Left	2.6	27	62	48	35	25	230 (73)	58 (56)	30.0	12.0
4	**16**	51	Male	ICB	Right	2.9	30	62	55	45	40	232 (128)	149 (104)	33.5	27.4
5	**19**	63	Male	CVI	Bilateral	2.6	25	63	55	43	46	258 (123)	97 (89)	38.6	15.4
6	21	82	Female	CVI	Right	6.4	27	63	45	30	50	131 (53)	113 (108)	37.2	22.2
7	32	85	Male	CVI	left	3.8	26	62	55	45	43	110 (53)*	121 (89)	N/A*	33.5
8	**33**	54	Male	CVI	Left	3.3	28	64	56	50	10	223 (129)	186 (178)	46.4	28.1
9	**37**	45	Male	CVI	Right	3.4	23	57	49	50	50	362 (193)	N/A	47.1	N/A
10	38	71	Male	CVI	Left	3.7	29	62	56	34	21	192 (109)	91 (78)	33.1	15.2
11	43	64	Male	CVI	Right	6.2	23	54	43	33	21	149 (72)	N/A	34.5	N/A

Numbers in bold indicate patients who practiced a type of imagery before study participation. Numbers in brackets indicate the amount of lines of the complete interview particularly related to MI. Int. = interview, yrs = years, MMSE = Mini-Mental State Examination, EBI = extended Barthel index, KVIQ = Kinaesthetic and Visual Imagery Questionnaire, vis. = visual, kin = kinaesthetic, min = minutes, N/A = not applicable, * = the first interview of this patient could not be recorded completely due to technical problems.

practice, the imagery just started in his head without a trigger:

> *"Just like that. While sitting in a train, or tram, everywhere." (Pat. 37, 1st interview).*

In relation to *position* taken for MI practice, seven patients identified a specific preferred position, two talked about a position related to the specific task to be imagined, and one patient spoke of other positions. The preferred position identified by patients can be related to the functional status of the individuals so that they felt safe and secure, for example, sitting or lying, or it might be related to the need to relax or "shut down" their thinking before starting MI practice. This contrasts with the changing task-specific position being adopted as preference, where the position mirrors the task starting position, for example, turning from supine lying to side lying.

> *"Basically, you could do that everywhere, don't you? In every, every position for sure. It depends on what you are going to do..... Sitting is a good starting position." (Pat. 16, 1st interview).*

During the second interview, after the two-week MI intervention period and the experience of MI, *location* and

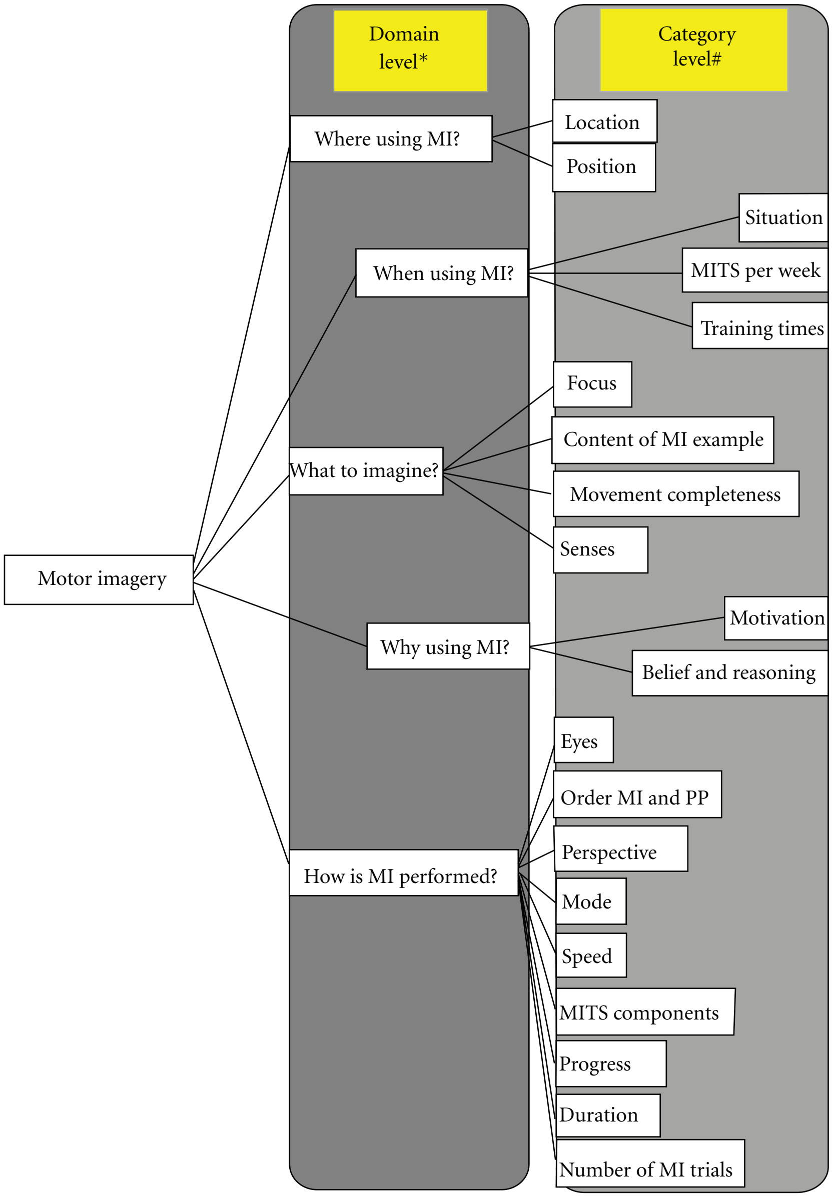


Figure 2: Final data analysis hierarchy tree. To remain readability, the level of the subcategories was not displayed but described in the text of the results section. §Patient information based on assumptions and on experiences after one practical MI example: sit-to-stand and back, MI = motor imagery. *Domain level refers to the English domain column in Table 2. #Category level refers to the English category column in Table 2.

position were again identified as the sole categories of the Where domain. However, brightness had not been identified as important this time, although a known environment was an additional idea voiced by patients as being useful. A known environment was preferred by patients as they would not be distracted by new things or having to explore a new environment first. They could focus solely on the task to be imagined.

> *"But,... in your usual environment, not where you have to absorb 100′000 other things, and you have to remember them, haven't you?" (Pat. 16, 2nd interview).*

The second interview data retained the subcategory identification of preferred position and task-specific position, indicating that after exposure to the MI technique, these domains remained important.

3.2.2. When Using MI?

Interview data relating to timing (WHEN) elicited three category themes: (a) *situation* (4 patients), (b) *MI training session per week* (2 patients), and (c) *times of the day* (4 patients).

In identifying when they carried out MI practice, 4 patients related this timing element to the *situation* or *location* (Where) category, showing that these domains were inter-linked. They talked about the need to concentrate on the MI task and therefore did not want to be disturbed by other tasks or noises (Pat. 32, Pat. 13, and Pat. 43). Some preferred a quiet environment or even wanted to be alone (Pat. 43, Pat. 6).

> *"No, no, before [that] I have to sit down, close the eyes and simply, ehm, yes, calm myself down and actually concentrate on: now I stand up." (Pat. 13, 1st interview).*

> *"Actually, when I'm alone at home and can fully concentrate." (Pat. 6, 1st interview).*

For three male patients, the When element corresponded to the number of *MI training sessions per week* indicating that MI training sessions should take place daily with MI repetitions at least 3 to maximum 10 times per day (Pat. 16, Pat. 43, and Pat. 13). Patients recommended short and frequent MI training sessions most likely as a consequence of their stroke, which let concentration emerge as a theme.

Relating to time of the day, some patients identified a *preferred time of the day*, which could be morning, afternoon, or evening, and for some the time of day related to tiredness, for example, when he/she cannot sleep during nights (Pat. 13, Pat. 6, and Pat. 38). A male patient, who used MI as marathon preparation before stroke onset, articulated that MI could be done at anytime of the day (Pat. 37). Furthermore, patients' diary entries from the MI intervention study link to the morning and evening times of the day for MI practice, in particular, when lying in bed before getting up and before falling asleep.

> *"Actually, [I can do it] always, when I take the time. But I think, it occupies the brain. And then, it does not make sense [to continue practicing MI] if you're too tired and you do it again." (Pat. 6, 1st interview).*

During the second interview after the experience of using MI, two additional areas emerged in relation to timing of practice. Two patients considered that MI could be practiced while doing other activities that are automatic and which did not need focussed concentration, for example, while mowing, raking leafs, watching television,and cycling (Pat. 13; Pat. 33). This could obviously relate to increased confidence and competence in the MI technique, but also to the patient's motor function level. Furthermore, one male patient mentioned the necessity of a stable emotional and mental condition to practice MI (Pat. 13). After the second interview the category *MI training sessions per week* included the subcategory *sporadic MI training* in addition. The subcategory *different time of the day* reported anytime and spontaneously as two new MI training times.

3.2.3. What to Imagine?

In relation to WHAT patients imagined, interview data revealed four categories: (a) the related *focus of a task* to be imagined with subcategories motor related (four patients) and cognitive-related (four patients), (b) *content of the imagined task* with subcategories imagined surroundings (ten patients) and the imagined person (seven patients), (c) *task completeness*, concentrated on the accuracy and the complete performance of the task to be imagined (eleven patients), and (d) *senses during MI* (nine patients).

MI had a cognitive related focus in imagined tasks before and after stroke onset. Before stroke onset, patients used imagery for marathon preparation, to organise staff, and work procedures (Pat. 37, Pat. 38, Pat. 33, and Pat. 19). After stroke onset, MI had mainly a motor related focus. Patients imagined simple single movements of fingers and toes, or trials to grasp and manipulate objects with the affected hand (Pat. 37, Pat. 19, and Pat. 16).

> *"And nothing happened, when you watched. Nothing happened. Only in my head I thought, yes, now I'm moving the toes. And the same with the fingers, did not it?" (Pat. 16, 1st interview).*

Experiences gained through the practical example of MI during the interview allowed patients to generalise the MI technique for further use. Two patients mentioned a possible application of the MI technique in different motor tasks and particular, to stair climbing (Pat. 32, Pat. 37). In the patient's case, stair climbing is one of the most aspired movements. During the second interview, there was an increase in patients' perceptions of the possibility of options to apply the MI technique to other motor tasks. Furthermore, three patients had already started using MI to imagine problem movements as simple single motions, for example, move affected arm and hand, and as complex movements, for example, walking.

Concerning the category *content of the imagined task*, the described imagined surroundings (subcategory) related to the respective task (five patients), seeing things of the actual room (two patients), described a bright or dark environment (six patients), or simply nothing (two patients). The second subcategory person emerged from describing seeing themselves doing the task (five patients), or seeing an additional person in their imagery, for example, the therapist, who was in the room where they practised MI (Pat. 37, Pat. 21). Interestingly, patients always saw themselves as a healthy persons without any paresis or abnormality in their movements, supporting literature reports on athletes with musculoskeletal injuries. Similar to dreaming, MI might be understood as allowing individuals to be the "whole" self and may have therapeutic benefit in that psychological domain, but this remains untested.

The *movement completeness* category yielded subcategories complete and incomplete, where ten patients imagined the complete motor task with all phases. Differences were mentioned for individual phases of the imagining task. While start and finish positions were sharp and vivid (Pat. 38, Pat. 33), more unfocussed images of the movements were described in between. This was particularly evident in the patient, who used imagery as marathon preparation prior to stroke.

> *"But the standing up, standing upright and sitting down again, that's what's inside my head. It stayed in my head better than the rest. The other phases were a little bit just a glimpse. Yes, where I got up and sat down, so the things inbetween it only was a glimpse." (Pat. 38, 1st interview).*

The interview data revealed aspects of the individuals' awareness of their *senses* during MI practice. Whilst three patients had no sensory awareness during imagining, which could be related to the concentration needed for the motor task performance, many patients identified no awareness of smell or taste sensations (seven patients). However, two patients described awareness of the sounds related to the motor task, for example, creaking of the chair or shoes (Pat. 37, Pat. 38).

3.2.4. Why Using MI?

Patient data showed two major themes in relation to WHY patients were interested in MI: (a) *motivation* (4 patients) and (b) *belief and reasoning*. Both themes are based on patients' prestudy beliefs and after having performed a practical example of MI during the interview. Three major "motivations" were identified by patients (4 patients): (1) being able to integrate an affected limb in daily routines (Pat. 19), (2) ease physical practice with MI preparation (Pat. 19), and (3) practice difficult or problematic movements in general (Pat. 37, Pat. 38, and Pat. 33).

Clearly, patients hoped that this technique might improve their physical function. In relation to *belief and reasoning,* patients identified that it might help them to gain confidence in performing a movement (Pat. 21), that previous exposure to MI had shown that it is an effective technique (Pat. 33, Pat. 38, and Pat. 37), and that the rationale to learn MI is that they can use it on their own to practice impaired movements or action procedures (Pat. 16, Pat. 43, Pat. 15, and Pat. 19).

> *"Then you can learn it [MI], then you can do it [MI], and you realise that something is changing." (Pat. 43, 1st interview).*

> *"It wasn't by far that way, but, ehm, the happiness was very great, wasn't it. And, yes, I tried it a lot, to move the fingers and all and watching and all, and when it only trembled a little bit, I was already happy, wasn't it." (Pat. 16, 1st interview).*

> *"That I can do it [MI] myself at home." (Pat. 15, 1st interview).*

Some patients, however, had opposing views and disbelief in the technique considered. One patient (Pat. 37) was very sceptical to MI use with paralysis, or on its own without physical practice. One patient went so far as to say *"...because it is something stupid." (Pat. 32, 1st interview)*

> *"You know, ..., you have to, yes, you have to do the tricks. You have to try, shift the weight. I always imagined it too. But it did not work because of it [MI]. If your limb is feebly, then it's feebly. Then you imagine it as long as you like." (Pat. 37, 1st interview).*

There were three patients, who had no real opinion about MI. One of those patients mentioned that someone would have to remind him permanently to practice MI. Otherwise, he would forget to do so due to his memory problems since stroke onset.

Following exposure to the MI technique, new ideas emerged from patients in relation to its usage (3 patients).

> *"I think I will continue to do this [MI]. If I recognise that this [MI] will make me more flexible (agil). I will benefit from MI and I will benefit for sure. Now, I would say, it [MI] gives me more confidence. Now, it's inside the brain." (Pat. 21, 2nd interview).*

3.2.5. How Is MI Performed?

The analysis on HOW patients conducted MI practice revealed a wide variety of elements.

(1) *State of Eyes during MI.* Six patients mentioned that they close their eyes during MI practice, some of them with the aim to improve concentration.

(2) *Order of Physical Practice and MI Practice*. Patients favoured MI trials "before" physical practice trials (2 patients). The advantage would be a better preparation for physical practice and therefore an easier physical practice performance.

(3) *Perspective of Imagination.* Patients used two perspective options during MI practice: internal perspective (4 patients) and external perspective (4 patients). In general, it is difficult for patients to describe the used perspective. Statements as *"as I would stand in the corner over there" (Pat. 16, 1st interview)* or *"I saw myself as a person, as a whole person" (Pat. 16, 1st interview)* indicated the external perspective. Here, the themes identified from the data support each other. The How and the What domains are linked together with their categories *mode* and *senses*.

(4) *MI Mode.* After performing the MI practice example during the first interview, five patients mentioned that they really felt the movement during imagination. This could be categorised as kinaesthetic MI and thus links with the What theme as described above.

(5) *Duration of MI Trials Compared to Physical Practice Trials*. The duration of MI trials was compared to physical practice trials in three subcategories: MI with a longer or shorter duration, and same duration like physical practice trials. A reason for these discrepancies regarding the trial duration of MI versus physical practice could be attributed to different levels of details imagined.

(6) *Components of an MI Training Session.* During interviews, it became clear that some patients can start immediately with an MI trial, whereas others needed a short moment of concentration and focussing beforehand. Therefore, a category titled *components of MI* was introduced.

(7) *Progress in Performing MI.* The oldest male patient, aged 85 (Pat. 32), mentioned that it would be helpful for him to start with a simple and short part of a motor task to imagine and add further steps after some consolidation. As this thought was confirmed by a second male patient during the second interview (Pat. 33), the category *progress in performing MI* was brought up.

(8) *Duration of MI Practice.* Related to the category *time of the day* when MI training is performed (domain When), it is the category *duration*. It describes the occasions where this category emerged with the *number of MI trials* below.

(9) *Number of MI Trials.* In general, patients reckoned that the training duration depends on the effort needed to practice MI (Pat. 6), but once a day seemed not enough. Patients suggested practicing MI several times (3-4) per day, with at least 2-3 subsequent MI trials (Pat. 13, Pat. 15, and Pat. 21). Both categories remained important in the second interviews. In particular, *duration of MI practice* was extended to of 4–6 minutes for 5–7 times per day (Pat. 13), organised in small breaks between working tasks. Furthermore, one male patient suggested a total MI intervention duration of up to six months to really learn the MI technique, aiming at using it for every daily movement or routine practice (Pat. 33).

3.2.6. Patients' Prestudy Knowledge, Experience, and Understanding of Imagery. A wide range of patients' prior exposure to MI was observed. Two patients reported active usage of MI, for example, during marathon preparation before stroke onset (Pat. 37), and to practice finger and toe movements after stroke onset (Pat. 16). Three patients had heard of MI or had seen athletes doing something what they interpreted as MI, in particular in ski racers just before their competition (Pat. 13, Pat. 6, and Pat. 33).

Four patients reported prestudy experiences with a type of mental imagery practice other than MI. One young female patient mentioned that she would dream, seeing herself walking without any impairment as she walked when she was healthy (Pat. 15). One middle-aged patient mentioned using autogenic training as stress-reducing technique (Pat. 13). Two males reported using a kind of self-talk or psyching-up technique to organise working procedures or for motivation purposes (Pat. 33, Pat. 13).

During the first interviews, patients offered various descriptions of what they understood or associated with the term MI, ranging from clear explanations to broad comments in both ways: positive and negative.

> *"Well, it's something normal. Like I would think about something different." (Pat. 33, 1st interview).*

> *"Surely close the eyes, imagine something and then practice." (Pat. 16, 1st interview).*

> "*Well, something I cannot do at the moment, that I imagine it, like I'm able to do it. Then it's working actively. That I picture or visualise the whole procedure in my head." (Pat. 6, 1st interview).*

> *"Well, one thinks it's something stupid." (Pat. 32, 1st interview).*

3.2.7. Post-MI Intervention Considerations. After the MI intervention, patients still found it difficult to describe what they were doing during MI (Pat. 19, Pat. 32). However, most patients found that it was simple and easy to perform, not exhausting (Pat. 15, Pat. 6, Pat. 19, and Pat. 16), and became automatic and natural after a while. Additionally, patients had started using MI for movements that were problematic for them, for example, climbing stairs, using affected hand/arm. Furthermore, six patients would recommend MI to other patients to practice depending on their mental capacity and their paresis level.

A minority of patients experienced MI during the intervention as difficult. Reasons were that they could not concentrate enough (Pat. 21), that they missed parts of the motor task to imagine and had to think about it/control all imagined details (Pat. 13, Pat. 32), and that physical practice trials were more easy to perform than MI trials of the same task (Pat. 32).

3.3. Patients' Learning Effects. The observed learning effects among patients were related to the interviews, practical example of MI, and the two- week MI intervention. Effects were related to the motor task, to MI, and to mental abilities. Some patients identified an increased confidence in performing the motor task due to the several mental rehearsals. The improved MI ability was recognised by patients (Pat. 32, Pat. 13, Pat. 21, Pat. 33, and Pat. 15), including the ability to apply MI to other motor tasks (Pat. 13), and not needing quiet environments anymore (Pat. 13). Four patients attributed improved cognitive abilities to the MI practice, for instance, being able to concentrate faster and for a longer period (Pat. 33, Pat. 38), being more relaxed (Pat. 21), being more awake or alert (Pat. 33), doing less day dreaming, and being more motivated to do other activities (Pat. 13).

> *"Because I had the impression, it works my brain a little. I had the impression, if I'm doing this, then I'm more awake somehow. Had the impression, not only my circulation is trained, my brain also. And that's just how it is, I have the feeling, it works my brain too." (Pat. 33, 2nd interview).*

3.4. Implications for Practice. Results from this research suggests that therapists may not expect patients to have experience with MI, but probably half of patients may have experience with some kind of mental practice, for example, autogenic training. Therefore, patients' previous mental practice knowledge should be evaluated before using MI in association with therapy sessions.

3.5. Interview Observations

Emotional Aspect. It is worth mentioning that patients actively reported on their personal and emotional situation during the interview. Even though, the patients' stroke event occurred some time ago, the description of the event, time in hospital, rehabilitation process, and retrospect became very emotional for several patients, for example, one female patient started crying.

MI-Related Aspect. It should be emphasised that patients saw themselves performing the motor task during MI. No patient described seeing herself/himself as a patient with impairments. All saw themselves as healthy as before stroke onset. Furthermore, related to the automatic MI, observed by some patients, performing MI of the motor task used in the intervention study started to occur suddenly in patients without conscious trigger.

Dissonance of Reporting. It is notable that one-third of the patients showed a dissonance in reporting. Their answers at the end of the MI-related part in the interviews could contradict answers from the beginning. This could be related to the insights on the abstract topic of MI gained during the interview and after having performed the practical example of MI.

4. Discussion

The established framework from sport psychology of where, when, what, why, and how MI is used was explored in patients after stroke in their chronic stage by conducting semi-structured interviews. The applied procedure offered the opportunity to acquire detailed information on the nature of patients' MI experiences, associations, MI training session elements (e.g., MI mode and state of eyes), and temporal parameters (e.g., duration of MI and number of MI trials). Patients imagined themselves as healthy individuals without impairment. They did not focus on surroundings during MI practice, and they reported to use positive imagery only. MI became automatic after the two-week MI intervention, and patients did not need focussed concentration and quietness as mentioned before the MI intervention.

Munroe and colleagues used a hierarchy with "where" as first level, "when" as second level, and "why" and "what" as third level [10]. In contrast, this investigation allocated the questions "where," "when," "what," "why," and "how" to the same hierarchy level, which was also used in the publications of Driediger et al. [13] and Nordin and Cumming [12].

Based on the results of Kosslyn et al., one may expect more patients having reporting the prior use of an imagery type used [9]. Two arguments could explain the different result: study patients in this current work were explicitly asked about knowledge and experiences of MI, not mental practice in general. Furthermore, we did not interview young, healthy students, but patients after stroke in the chronic stage of the disease.

4.1. Where Using MI?

Patients after stroke liked to practice MI at home or when alone, which is in line with athletes with musculoskeletal injuries in Driediger et al.'s investigation [13]. Furthermore, athletes practiced MI mainly during physiotherapy sessions before finishing an exercise, whereas stroke patients did not mention using MI during therapy at al. In the current analysis, *location* and *position* were identified as WHERE categories, whereas Nordin and Cumming and Driediger et al. did only focus on "location" [12, 13].

4.2. When Using MI?

Similar to athletes with musculoskeletal injuries, patients considered that MI could be practiced while doing other activities that are automatic, and which did not need their focussed concentration, for example, watching television, driving a car [13]. This insight was reported by patients during the second interview only. We assume that the delayed insight could be caused by the MI training during the intervention period, where patients gained MI knowledge, practice, and experience. A categorisation of the WHEN domain by *situation*, *MI training session per week*, and *training time of the day* was not reported by Driediger et al. for athletes.

4.3. What to Imagine?

Driediger and colleagues did not describe the domain HOW as MI performed [13]. Therefore, their domain WHAT incorporated five categories including session, effectiveness, nature, surroundings, and imagery type. The latter one was classified to the domain How in the current investigation. Driediger et al.'s category *session* described the length of the MI practice between 5 and 30 seconds for athletes with musculoskeletal injuries. In contrast, patients after stroke several MI practice sessions per day with a length of up to 15 minutes were accounted in the category *duration* (domain HOW). Whereas athletes in category *nature* reported "positive" and "negative" imagery, patients mentioned after stroke "positive imagery" only. Both groups indicated seeing themselves as healthy individuals or athletes possessing their preinjury motor function and competition level. Additionally, surroundings during MI practice did not play an important role for athletes with musculoskeletal injuries and patients after stroke, which could be due to focusing on the healing process in athletes and the MI learning process in patients.

"Type" in the study of Driediger et al. included reporting on MI *perspective* and *vividness* of imagery [13]. Both categories were classified to the domain HOW in the current investigation.

4.4. Why Using MI?

Paivio's framework on effects of imagery on human motor performance influenced Driediger et al.'s classification of WHY doing athletes with musculoskeletal injuries MI [11, 13]. Driediger et al., [13] devised cognitive-specific imagery as a help to perform rehabilitation exercises. MI was before and simultaneously executed with physical practice aiming at skill enhancement in athletes with musculoskeletal injuries. "Cognitive general" imagery was used to maintain the ability to carry out activities associated with their sport. "Motivational-specific" imagery was used to visualise goal and related activities and to maintain motivation by imagining full recovery and future competitions. "Motivational general" (arousal and mastery) was used to continue rehabilitation, even in painful conditions and to keep mentally tough. In athletes with musculoskeletal injuries, motivational imagery was not used to enhance confidence. In the current investigation, patients after stroke rarely used MI before the MI intervention study. Therefore, an allocation to "Motivational general" based on the traditional framework is difficult. Patients' reasons to use imagery included gaining self-confidence to perform the motor task, easier physical practice performance after MI, and being more alert. These indications are in line with the results of the review from Feltz and Landers [25]. The authors emphasised that with the help of imagery, the performer is better prepared for the following action, through shorter reaction times, lower sensory threshold, appropriate tension levels, focused attention, and an increase of muscle action potentials. Driediger and colleagues also mentioned three more categories of the domain WHY: healing with images of the physiological recovery process, pain management, and injury prevention. None of them could be explored in patients after stroke [13].

4.5. How Is MI Performed?

Munroe et al.'s and Driediger et al.'s reports did not use the HOW domain [10, 13]. In the current investigation, nine categories were identified in this domain, from which two were included in the What domain by Driediger et al. (MI type, MI perspective) [13]. In this current work, "HOW" aims to describe characteristics for the MI intervention design, which is contradictory to the "HOW" domain identified by Nordin and Cumming [12]. Their "HOW" domain included three categories related to triggers that help to obtain images, to relate MI to symbolic images, and to design graded levels of images. The latter can be interpreted as compounding a basic visualisation and adding up more details of the image and sensation. However, we believe that the MI experience in patients after stroke cannot be compared to athletes' MI experience. Therefore, an in-depth description of their MI trigger and MI acquirement cannot be expected. Often patients reported that they had to start MI of the motor task by themselves. After the MI intervention, MI started automatically regardless the patients' current situation, location, or activity.

4.6. Linkage of Domains

During the data analysis, it became clear that several considered domains are related.

WHAT and HOW. Although How comprises categories describing the design of an MI training, it also contains the categories *perspective* and *MI mode* that could be associated with the category *senses* in the domain What. Munroe et al. and Driediger et al. did not describe a How domain [10, 13]. However, Driediger and colleagues did define "perspective" and "mode" under the domain What, but termed *mode* as *type*.

WHEN and WHERE. Patients information for the domain When was closely related to the s*ituation* or *location* in the domain Where

WHEN, WHAT, and HOW. For the domain When patients reported the number of *MI training sessions per week*, *number of MI trials*. Agreements for concentration (What) were mentioned and short but frequent MI training sessions recommended (How).

4.7. Limitations.

It could be argued that the nested study design limited the diversity of patient information gained and biased patient selection. However, all eleven patients showed a wide age range from 31 to 85 years, different motor function level, and time periods from stroke onset to study entry (1.3 to 6.2 years). Furthermore, Guest et al. showed in their study with 60 in-depth interviews that data saturation occurred within the first twelve interviews already, suggesting that the sample considered in this investigation is sufficient [26]. Moreover, participating in the related pilot RCT provided more detailed data on patients MI ability and offered the opportunity to confirm patients' statements from the first interview, for example, regarding MI content, with responses from the second interview.

The interviewer's MI knowledge and her function as therapist in the related MI intervention study could have influenced formulating and asking questions in an attempt to cue certain answers and information. We assume that patient responses were not influenced by the interviewer as patients expressed their negative MI experiences honestly during the second interviews.

No category related to MI ability or vividness of imagery could be confirmed based on the patients' interview data. Nevertheless, a link to the category *movement completeness* could be drawn, which classifies incompletely or completely seen movements. However, we believe that the interviewed patients did not have the detailed knowledge on this particular MI characteristic after the short MI intervention compared to continuously MI-trained athletes.

Despite constrains in qualitative research involving patients with different levels of speaking impairments, which could limit the richness and depth of responses, it is important to apply qualitative techniques, as confirmed by the results obtained in this investigation.

5. Conclusion

Until now the imagery framework has been explored in various sports disciplines, but not in patients after stroke, who are not trained in using MI routinely. MI understanding and usage differs between athletes and patients after stroke. It is essential to determine MI understanding and ability in stroke patients, in order to design tailored MI interventions. In this work, the framework on where, when, what, why, and how MI is used has been adopted from sports psychology and applied to organise information gained in semistructured patient interviews. It became clear that MI is not established in patients after stroke. MI was not used to support motor function recovery. In rare cases, MI appeared spontaneously and was used for simple movements, for example, grasping. Patients related MI to a mental technique aiming at practicing movements that are not possible at the moment or gain confidence in difficult movements. Furthermore, patients imagined themselves as healthy individuals without impairment. They did not focus on surroundings during MI practice, and they reported to use positive imagery only. After MI training, patients became more flexible regarding their location and position during MI practice. In most cases, MI became automatic after the intervention, and patients did not need focussed concentration and quietness as mentioned in the first interview. MI use is clearly underresearched in stroke rehabilitation. Future MI intervention studies for patients after stroke should include an evaluation of patients' MI ability and an MI familiarisation session to learn essential MI training session elements and their characteristics, for example, MI perspective, MI mode. Furthermore, MI interventions should start with simple motor tasks and less MI trials repetitions. After a consolidation phase, MI trial repetitions could be increased, and more complex motor tasks could be imagined.

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Research Article

Constraint-Induced Movement Therapy (CIMT): Current Perspectives and Future Directions

Aimee P. Reiss, Steven L. Wolf, Elizabeth A. Hammel, Erin L. McLeod, and Erin A. Williams

Division of Physical Therapy, Department of Rehabilitation Medicine, Emory University School of Medicine, Atlanta, GA, USA

Correspondence should be addressed to Aimee P. Reiss, aimee.reiss@emory.edu

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Constraint-induced movement therapy (CIMT) has gained considerable popularity as a treatment technique for upper extremity rehabilitation among patients with mild-to-moderate stroke. While substantial evidence has emerged to support its applicability, issues remain unanswered regarding the best and most practical approach. Following the establishment of what can be called the "signature" CIMT approach characterized by intense clinic/laboratory-based practice, several distributed forms of training, collectively known as modified constraint therapy (mCIMT), have emerged. There is a need to examine the strengths and limitations of such approaches, and based upon such information, develop the components of a study that would compare the signature approach to the best elements of mCIMT, referred to here as "alternative" CIMT. Based upon a PEDro review of literature, limitations in mCIMT studies for meeting criteria were identified and discussed. A suggestion for a "first effort" at a comparative study that would both address such limitations while taking practical considerations into account is provided.

1. Introduction

Recent advances in stroke rehabilitation research, including constraint-induced movement therapy (CIMT), have the potential to change traditional therapeutic approaches in clinical practice. However, communicating best practices and implementing change remain significant challenges for both researchers and practicing clinicians to overcome. In a recent Canadian study, Menon et al. [1] found that, despite the evidence of best practice in stroke rehabilitation, the implementation of best practice in the clinic was inconsistent and underutilized, as clinicians continued to apply traditional neurodevelopmental techniques in the treatment of individuals after stroke. Barriers to incorporating evidence-based practice (EBP) into clinical settings are well documented and fall under two general categories: individual clinician barriers and organization barriers [1–3]. Lack of time and resources is often cited by clinicians as primary limitations to reading or searching the literature [1–3] as well as self-efficacy. In this context, self-efficacy means the degree to which an individual clinician feels capable of searching, reading, analyzing, and implementing evidence-based practice into her daily clinical practice and thought processing. Low self-efficacy may be more prevalent in clinicians who have been working for 15 or more years because of lack of formal education in EBP skills [1, 2]. Organizational barriers can include lack of computers or access to research databases, the absence of active research in clinical settings and limited encouragement of professional development, with a growing emphasis on productivity [1, 2]. The combination of time constraints, productivity pressures, volume of research available, and a dearth in EBP skills may, over time, create an even greater gap between best evidence and current practice [1]. National and international guidelines for evidence-based practice following stroke can assist clinicians in determining best practice by compiling recent advances in stroke research. These guidelines are easily accessible and decrease the burden on clinicians to search and assess the literature themselves. However, they may not always provide sufficient evidence or information regarding a particular intervention, and there may not be a shared consensus among guidelines.

In the case of constraint-induced movement therapy, drawing a solid conclusion after reviewing prominent stroke guidelines is difficult. For instance, in a scientific statement from the American Heart Association [4], CIMT is recommended for chronic stroke patients with greater than 10 degrees finger extension, but no parameters of treatment are provided. Australian stroke guidelines paint a less conclusive picture of CIMT, concluding that CIMT is effective with more than 20 hours of training, but possibly detrimental when provided very early in the rehabilitation process [5]. Here again no treatment parameters were offered for the delivery of CIMT and the lack of methodological consistency in the literature was noted. New Zealand guidelines briefly mention CIMT as a possible rehabilitation approach, but make no recommendations regarding patient criteria or the parameters to deliver CIMT [6]. Canadian guidelines, updated in 2010, offer the most specific details for patient criteria and protocol parameters for signature or modified CIMT (mCIMT) in early stroke rehabilitation [7]. These differences yield a lack of clarity regarding recommendations for CIMT and may in part be precipitated by the lack of methodological quality in the modified CIMT literature. The purpose of this paper is therefore multi-fold: (1) present current perspectives of signature CIMT and the evolution of mCIMT; (2) discuss limitations in current CIMT literature by using PEDro criteria as a basis to; (3) suggest an "alternative" form of modified CIMT, which can subsequently be compared to the signature form in a "head-to-head" comparison, first in preliminary studies and then as a formal clinical trial. This consideration is important since such an effort has not been formally undertaken.

1.1. Current Perspectives of Signature CIMT and the Evolution of mCIMT. Constraint-induced movement therapy (CIMT) is a widely explored treatment protocol to increase functional use of the more impaired upper extremity (UE) for persons with hemiparetic stroke. The theoretical basis for CIMT was developed through early research in nonhuman primates from which the concept of learned nonuse following limb somatosensory deafferentation emerged [8, 9]. Taub and colleagues described the learned nonuse phenomenon as a behavioural adaptation that occurs in response to the loss of sensory feedback due to a decrease in coordinated movements, negative reinforcement from unsuccessful attempts with the impaired limb, and positive reinforcement resulting from success in compensatory movement patterns with the unimpaired limb. The result of this sequelae is a decrease in functional use of the impaired UE [10]. This undesirable adaptation was overcome in monkeys by restraining the insensate limb, thus forcing them to use the impaired UE [11].

According to Taub and colleagues [12], learned nonuse occurring after somatosensory deafferentation in nonhuman primates is comparable to that seen following central nervous system (CNS) insult in humans, such as after stroke. In the first application of a treatment technique to overcome learned nonuse in humans, a patient with hemiparetic stroke was asked to perform functional tasks with the more impaired UE with restraint of the less affected UE [13]. Restraint, in addition to encouraging without formally training massed practice of the impaired UE, resulted in what Wolf et al. called "forced use" [14].

The protocol has evolved to specifically include repetitive and adaptive task practice under clinical supervision. These additional structured elements collectively define the current concept of CIMT. Repetitive task practice (RTP) is continuous blocked practice of a specific functional task, usually for a period of 15–20 minutes. Adaptive task practice (ATP), or shaping, uses a step-wise approximation method, breaking down tasks into successive manageable components to improve overall proficiency [15, 16]. Based upon the underlying operant conditioning through provision of therapist feedback, shaping fosters patient problem solving, resulting in self-motivation to use the affected limb [16]. This intensive practice fosters motor relearning and has been shown to promote neural plasticity in the CNS [15]. Successful application of CIMT is thought to induce a use-dependent increase in cortical reorganization of the areas of the brain controlling the most affected limb [17, 18].

Several studies, primarily in mild to moderately impaired survivors of stroke, have demonstrated clinically relevant results [12, 19–21]. However, limitations, such as small sample sizes within trials, variations in time since stroke, and alternative CIMT protocols, weakened the ability to draw significant conclusions about pertinent findings [22, 23]. In 2006, results from the first Phase III, multisite, randomized clinical study, the EXtremity Constraint-Induced Therapy Evaluation (EXCITE) trial, were published and showed statistically and clinically relevant confirmation of the efficacy of CIMT in patients three-to-nine months posthemiparetic stroke [24].

Signature CIMT, developed by Taub [12, 25] and later used in the EXCITE [24] trial, included restraint of the less impaired upper extremity by donning a protective safety mitt for 90% of waking hours over a two-week intervention period. Subjects were also required to participate in six hours/day (five days/week) of ATP and RTP [10, 24]. Some researchers have criticized this signature protocol as being impractical in clinical settings [26–31]. Patient tolerance, mitt wearing adherence, feasibility in clinics, and reimbursement issues have been emphasized as key weaknesses of the signature CIMT protocol, thus potentially acting as barriers to more pervasive clinical implementation [32, 33].

In response to these critiques, a number of "modified" versions have arisen to address the issues presented by the signature form of CIMT. Some investigators altered intensity protocols by distributing total treatment time over a longer duration. For example, Wu et al. [29, 34, 35] decreased the intensity to two hours/day (five days/week) but increased duration to three weeks, which required only six hours/day of upper extremity restraint. Page et al. [26, 33, 36] increased treatment duration to 10 weeks, with 30 minutes of intervention per day, three days/week and reduced mitt restraint to five hours/day. Other investigators expanded the inclusion criterion for relative chronicity. Ro et al. [37] included subjects 14 days after stroke, and Miltner et al. [38] included subjects up to 17 years after stroke. While all of these modifications claim to have shown effectiveness in improving motor function, these studies, like early signature CIMT research, are also limited by small sample sizes. Of all trials included in previous reviews of CIMT, only two studies had greater than 30 participants [22, 23].

Despite significant variability in protocols, each form of treatment delivery claims the name "modified" CIMT [35, 39]. The issue therein is the lack of standardization by which to establish a consistent reference point for monitoring treatment dosage, creating confusion among the researcher, therapist and reimbursement communities. Therefore, an analysis of existing modified CIMT protocols, to devise a reasonable synthesis of approaches called "alternative" CIMT, should be performed and becomes a necessary precursor before a best model alternative intervention that incorporates key elements, such as intensity, duration, and subject chronicity [40, 41], can be constructed. This best model alternative protocol can then be formally compared to signature CIMT to determine if an alternative, more feasible approach is equally effective.

An important first step, intended to increase the veracity of these future studies, is the analysis of the methodological quality of current CIMT literature using a valid and reliable tool to determine worthy inclusion in development of the alternative treatment protocol. To build a strong study at any level, including only the highest quality literature as a foundation for study design and in support of findings, becomes a critical consideration. Not only do these factors increase the integrity of any immediate study, but also that of future studies. Unlike previous reviews which explored only CIMT efficacy [22, 23], we sought to critically analyze existing CIMT methodologies in order to systematically determine specific deficiencies within articles. Worthy articles can then be selected for use in determining an alternative form CIMT, which can then compared to the signature form in a "head-to-head" comparison.

The evaluation tool chosen for analyzing methodological quality of CIMT research was the Physiotherapy Evidence Database (PEDro). PEDro applies 11 criteria, 10 of which are scored (see Appendix A) to assign a quantitative measure of study strength [42]. This particular set of criteria was chosen for its specificity to physical therapy literature; use by novice and expert researchers alike; reliability [43]; strength in assessing methodological quality specifically in stroke literature [44].

Although the authors did not intend to perform a systematic review of the CIMT literature, several articles were selected from 1998–2008 as a comprehensive sampling to use as the basis for this discussion. The list of CIMT literature was compiled using the following electronic databases: PubMed, Cochrane Library, MEDLINE, and Ovid. Key terms included constraint-induced movement therapy, modified CIMT, hemiparetic stroke, and constraint-induced therapy.

Approximately 75 studies were deemed relevant for further review, based upon title and abstract containing CIMT or "modified" CIMT. Studies were excluded if all three components of CIMT (ATP, RTP, and restraint) were not administered in at least one group; they contained paediatric participants (<18 years of age), used subjects other than patients with stroke, were systematic reviews/meta-analyses, or were nonexperimental literature (case studies, letters to the editor, or perspectives). Experimental literature accepted for use in this review included Sackett's levels of evidence: 1b, 2b, and 3b (see Appendix B) [45]. After employing this procedure, 27 articles, published between 1999 and 2008, were chosen for inclusion in this discussion [24, 26–31, 33, 34, 37, 38, 46–61].

Therapist raters with comparable experience in research design, independently rated each of 27 CIMT articles using PEDro criteria. A series of detailed discussions regarding the nature and interpretation of these criteria preceded the actual rating exercise. All raters were blinded to each other's assessments. A "yes" was given for each criterion the rater believed was satisfied by the article. Total scores reflected the total number of "yes" answers given on eligible criteria (2–11 are considered "eligible" for scoring). One reviewer compiled the results of the three raters. Scores were not discussed among raters prior to compilation or statistical analysis. A post-hoc analysis showed that raters could not agree upon whether some studies met three particular PEDro criteria: baseline similarity between groups, outcome measures obtained for at least 85% of participants, and clarity regarding successfully meeting the "intention to treat" directive (see Appendix A).

There may be several explanations for interrater discrepancies. Lack of clarity in some PEDro operational definitions may have contributed to varying interpretations among reviewers. Hence there may have been some uncertainty about whether studies clearly articulated and implemented an intention to treat strategy. A discussion amongst raters suggested that disagreement between raters may have been precipitated by alternative interpretations or poorly defined aspects of methodologies or outcomes. Such misinterpretations could be overcome through clearer precision in the delineation of methods. For criterion four (baseline similarity), some articles calculated significant differences between groups for only a few characteristics, but claimed overall "baseline similarity." This discrepancy in approach left the reader unsure if the criterion was completely fulfilled. Raters were commonly uncertain if outcomes measures were collected in at least 85% of subjects (criteria eight). Finally, report of attrition (criteria nine) was another source of reader confusion due to unclear documentation. Subject dropout had to be inferred in some cases from tables, rather than explicitly stated in the text.

Additionally, raters agreed that blinding of evaluators to subject allocation and intervention received were not adequately addressed in the current review. Collectively, these methodological weaknesses present a challenge for clinicians to confidently interpret and apply the principles of these alternative forms of CIMT. These discrepancies became the basis for the selection of elements that needed greater clarification and inclusion in an alternative form of CIMT against which one can then undertake a comparison with the signature CIMT.

1.2. Efforts to Create a Standardized Alternative Form of CIMT. A recent article attempted to compare a version of modified CIMT to signature CIMT. Barzel and colleagues [62] compared signature CIMT to a 4-week home-based modified CIMT program (CIMThome). CIMThome patients and a family member received an initial day of training from a physiotherapist regarding the two primary components of signature CIMT: shaping and constraint of the nonaffected upper extremity. CIMThome patients and their caregivers then performed a self-managed program at home for four weeks, with weekly visits by the physiotherapist to supervise and advance therapeutic exercises as appropriate. Despite the home-based program, patients still received nearly 15 hours of supervision from a physiotherapist. Results showed CIMThome to be as effective as signature CIMT; however, the sample size was small with just seven chronic stroke patients in the CIMThome group.

Hosomi and colleagues also developed a self-training protocol using elements of signature CIMT [63]. Forty patients were recruited based on signature CIMT criteria. Patients were then instructed in a self-training protocol that included instruction in shaping tasks to address individual limitations. The protocol consisted of 20 minutes of self-training per shaping task, culminating in 10–15 different training tasks per day (five hours a day for 10 consecutive weekdays). Direct supervision by a physiotherapist occurred every 20 minutes to evaluate patient performance and advance therapeutic exercise as appropriate. Results showed significant improvements on the Fugl-Meyer Assessment, the Wolf Motor Function Test, and The Motricity Index. However, a major limitation of this study was having no comparison to a control group or other modified CIMT protocol. Therefore, the weaknesses of methodology discussed in this paper have still not been addressed in recent studies either, and a need exists to generate a best-model alternative CIMT option that incorporates weaknesses extracted from the literature.

1.3. Implications. In designing future studies, methodologies must be clearly defined and controlled to improve clarity for readers and replication for clinical researchers. Specifically, discrepancies were noted for attrition and diffusion of intervention, and report of baseline statistics.

To provide evidence-based practice, increased numbers of therapists are accessing and reading clinical trials in order to choose appropriate interventions. When attempting to qualify an article's strength, clinicians and researchers may use a system like PEDro. Therapists may be assumed to use high- rather than low-scoring articles when choosing interventions. However, if criterion satisfaction is unclear, interpretation is left to the reader, leading to discrepancies in perception of the value of a clinical trial that can ultimately impact clinician interest in utilization of treatment protocols. A more appropriate course of action would be to place responsibility upon researchers to give greater attention to clarity when describing methodological considerations.

Recently, within the field of neurorehabilitation, there has been a call to improve the value of studies [64, 65]. Dobkin [65] proposed performing a thorough qualitative assessment of current literature as a key to accomplishing a more systematic approach to method design, to increase the integrity of multisite randomized clinical trials for motor interventions. In the case of CIMT, we have performed a comprehensive literature search and assessed the methodological quality of several articles to determine specific deficiencies within the articles.

Secondarily, the most substantial elements that might serve as the foundation of a "best model" alternative CIMT protocol can also be proposed. Three articles in our mCIMT review scored 8/10 on the PEDro scale [29, 31, 34], the highest scores in our review. The frequency and intensity of the modified CIMT interventions were very similar across these studies: 2 h/d, 5d/wk for 3 wk. This treatment intensity may be more feasible and practical than signature CIMT. In addition, we propose further elements drawn from signature CIMT, including two hours of home task practice for three days per week for three weeks including specification and rationalization for this practice. Participants in this alternative form of CIMT would also undergo 30 minutes of a nonspecific but documented functional activity six days per week and wear the restraining device 90% of waking hours. This dosing approximates 75 hours over a three-week interval using a distributed practice model that would be comparable to almost 80 hours (up to six hours per day, five days per week for two weeks in a clinic/laboratory environment in addition to about two hours per day for 10 days of home-based activities) of signature CIMT. For both interventions, restriction of better limb use would occur for 90% of waking hours throughout the intervention period. Inclusion criteria would match that established for the EXCITE Trial [24]. The alternative CIMT plan would include therapist guided on-sight training for two hours the first day of each of three weeks with home based assignment of mutually agreed tasks throughout the remainder of the week for each of three weeks. Participants in both groups would be evaluated before and after the intervention with subsequent followups at 3 and 6 months after intervention. The evaluator would be blinded to group and the selected outcome measure would be standardized. Dropouts would have last values carried forward (imputation), a typical procedure in intention to treat studies. The study would be powered based upon the selected outcome measure. For example, if the outcome was the WMFT, a reasonable change could be a 30 percent reduction in median time to complete tasks associated with a patient impression of percent improvement in function as suggested by Fritz et al. [53]. Collectively, such a comparison would address several issues. All the limitations observed in the present PEDro review would be overcome, dose equivalency would be established, a reasonable home based, patient driven program could be standardized and compliance measured, and immediate and intermediate end points would optimize difficulties often encountered in tracking participants over a longer period of time. A future pilot study will assess the feasibility and efficacy of this proposed "best model" alternative CIMT protocol to signature CIMT with the intent to develop a signature mCIMT protocol.

2. Possible Limitations

The exclusion of meta-analyses and case-studies presents a possible limitation to the extensiveness of the PEDro review. The PEDro system used in this review pertained only to single clinical trials. Moreover, while there were only 27 articles comprising this review, such a number is relatively high compared to previous systematic CIMT reviews. Three existing systematic reviews in CIMT research, conducted by Hakkennes and keating [22], Bonaiuti et al. [23], and Corbetta et al. [66], included 14, nine, and 18 studies respectively, and each review used only two reviewers. In the Hakkenes and Keating [22] and Bonaiuti et al. [23] reviews disagreements were discussed until scores were agreed upon. Unlike these studies, disagreements between raters in this study were viewed as valuable, and utilized to note limitations in current research methods in hopes that the design of future studies might address these considerations. In addition, the Corbetta review [66] described a majority of the articles chosen as "underpowered and imprecise," making the case for a larger RCT and underscoring the weak methodology of the CIMT literature.

3. Conclusion

The model proposed in this paper is not only useful for analysis of CIMT literature, but may serve as a template for future studies in any genre of scientific inquiry. The quality of CIMT literature, specifically modified and signature methods, was examined closely in an attempt to increase the integrity of a future pilot study comparing a "best model" alternative CIMT protocol with the signature form of CIMT. A direct comparison approach that addressed limitations in the literature extracted from the PEDro review was suggested. Efforts by researchers to improve methodology and standardization of protocols can greatly assist the practicing clinician in analyzing EBP and incorporating best practices into clinical practice. Establishing a standardized best-model alternative CIMT protocol would also allow stroke guidelines to make clearer, more definitive recommendations regarding CIMT.

Appendices

A. PEDro Criteria

(1) Eligibility criteria were specified.

(2) Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received).

(3) Allocation was concealed.

(4) The groups were similar at baseline regarding the most important prognostic indicators.

(5) There was blinding of all subjects.

(6) There was blinding of all therapists who administered the therapy.

(7) There was blinding of all assessors who measured at least one key outcome.

(8) Measures of at least one key outcome were obtained from more than 85% of the subjects.

(9) All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by "intention to treat."

(10) The results of between-group statistical comparisons are reported for at least one key outcome.

(11) The study provides both point measures and measures of variability for at least one key outcome [42].

B. Sackett's Levels of Evidence

Levels of evidence for interventions [67]:

(1a) systematic reviews of randomized controlled trials (RCTs),

(1b) individual RCTs with narrow confidence interval,

(2a) systematic reviews of cohort studies,

(2b) individual cohort studies and low-quality RCTs,

(3a) systematic reviews of case-control studies,

(3b) case-controlled studies,

(4) case series and poor-quality cohort and case-control studies,

(5) expert opinion.

Conflict of Interests

The authors report no of interests. The authors alone are responsible for the content and writing of the paper.

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Review Article

How Physically Active Are People with Stroke in Physiotherapy Sessions Aimed at Improving Motor Function? A Systematic Review

Gurpreet Kaur,[1] Coralie English,[1,2] and Susan Hillier[1,2]

[1] *School of Health Sciences, University of South Australia, P.O. Box 2471, Adelaide, SA 5001, Australia*
[2] *International Centre for Allied Health Evidence, School of Health Sciences, University of South Australia, P.O. Box 2471, Adelaide, SA 5001, Australia*

Correspondence should be addressed to Coralie English, coralie.english@unisa.edu.au

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Background. Targeted physical activity drives functional recovery after stroke. This review aimed to determine the amount of time stroke survivors spend physically active during physiotherapy sessions. *Summary of Review*. A systematic search was conducted to identify published studies that investigated the use of time by people with stroke during physiotherapy sessions. Seven studies were included; six observational and one randomised controlled trial. People with stroke were found to be physically active for an average of 60 percent of their physiotherapy session duration. The most common activities practiced in a physiotherapy session were walking, sitting, and standing with a mean (SD) practice time of 8.7 (4.3), 4.5 (4.0), and 8.3 (2.6) minutes, respectively. *Conclusion*. People with stroke were found to spend less than two-thirds of their physiotherapy sessions duration engaged in physical activity. In light of dosage studies, practice time may be insufficient to drive optimal motor recovery.

1. Introduction

People with stroke spend less than a quarter of their day engaged in physical activity in rehabilitation centres [1, 2]. Studies conducted internationally over many years have shown that the time spent by people with stroke in therapy and in contact with therapists during the working day is very little [1–4]. Bernhardt et al. [1] found that people with stroke spent only 5.2 percent of the working day in contact with therapists in an acute stroke unit which equates to 0.5 hours of a nine-hour observation period. Similarly, Thompson and McKinstry [4] found that people with stroke in an inpatient rehabilitation unit spent only 1.2 hours of an 11-hour observation period in therapy. However, an observational study investigating the use of time in physiotherapy sessions specifically, reported that people with stroke spend between 21 percent and 30 percent of therapy sessions inactive [5]. Many studies have identified therapy sessions as being the most active part of the day and therefore provide the greatest opportunity to maximise physical activity levels. Therefore, this review was important to determine exactly how active people with stroke are in their physiotherapy sessions during stroke rehabilitation.

Targeted physical activity drives functional recovery after stroke. There is now strong evidence that more time spent in task-specific therapy after stroke improves functional outcomes [6, 7]. Furthermore, high repetitions of a task-specific physical activity have been shown to facilitate positive neuroplasticity in stroke survivors [8–10].

In light of this knowledge, and the fact that clinical guidelines for stroke management include recommendations to maximise active therapy time [11], it is important to determine just how active stroke survivors are in therapy sessions aimed at improving motor function. Therefore, the aim of this review was to synthesise the current evidence about the total amount of time spent by people with stroke engaged in physical activity (total active time) and time spent engaged in different physical activity categories during physiotherapy sessions in stroke rehabilitation.

Table 1: Search terms used to identify published studies which reported data on therapy content and duration.

Stroke or CVA or "cerebrovascular accident*" or "cerebrovascular disorder*" or "cerebrovascular disease*" or hemip*
And
rehabilitation or physiotherapy or "physical therapy"
And
"time use" or time or "therapy* time" or "time taken" or "activity* time" or "time spent",
And
activity* or "physical activity*" or "active therapy" or "motor activity*" or exercise or "exercise program" or "exercise therapy" or "therapy content" or intensity or repetition*
Or
"behavioural mapping" or "behavioral mapping"

2. Methods

Published studies of all designs were identified by entering various search terms (Table 1) in the following electronic databases: CINAHL, AMED, MEDLINE, and EMBASE (Classic + Embase from 1947 to 2010, week 38). Preliminary searches were conducted in August 2010 to find the appropriate search terms. The final search was completed on the 11th of December, 2011. The reference lists of studies which met the selection criteria were searched for potentially relevant publications. Searches were limited by years of publication (1990 to current), English language, and participants' age group (18 years and over). The authors of studies which reported both therapy content and therapy time but had insufficient data for the purposes of this systematic review were contacted for additional data.

Studies were included if (1) participants were adults receiving rehabilitation after stroke, (2) physiotherapy was provided in inpatient rehabilitation or an acute care hospital, and (3) data relating to both the therapy content (type of physical activity subcategories), and the amount of time spent in different physical activity categories during physiotherapy sessions was reported (i.e., studies reporting content of therapy only or total duration of therapy sessions only were not included).

Critical appraisal of the relevant articles was conducted using a modified evidence-based learning critical appraisal checklist [12]. This tool assesses the quality of observational studies in four categories: population, data collection, study design, and results. The factors which were most likely to contribute bias to the studies were chosen from the original critical appraisal tool. Two additional criteria were added: "concealment of study purpose to the participants" as this would reduce any bias arising from changes in usual practice and "involvement of an independent person observing the therapy sessions" which would reduce the risk of bias of overestimation of therapy duration. A copy of the critical appraisal tool as it was applied in this review appears in the Appendix. Two reviewers critically appraised the included studies independently. Justification of results from both reviewers was discussed and when disagreement occurred, a consensus was reached by discussion. Where further information was required to clarify criteria (e.g., whether the assessor was an independent person), authors were contacted directly. Where consensus could not be reached or criteria remained ambiguous, the opinion of a third reviewer was sought.

Data from the included studies were extracted including total therapy session duration, time spent in different physical activity subcategories, and total inactive time. The percentage of total active time was calculated using total time spent in physical activity subcategories in a therapy session. The total active time was averaged across studies, where data were sufficiently homogenous.

3. Results

The search yielded 2534 hits of which 61 studies were potentially relevant after reviewing titles and abstract (see Figure 1 for flow chart). After removing 13 duplicates, 48 relevant full-text articles were obtained and assessed against the selection criteria by one reviewer. A total of 28 studies were excluded because of their outpatient setting, and/or lack of data on therapy content or duration. Two reviewers assessed the full text of the remaining 20 studies and independently made a decision about studies to be included in the review. A third reviewer was available to adjudicate any disagreements, but this was not required. The reference lists of the included seven studies were scrutinized, but no further relevant publications were identified. An expert check was also conducted, but no further studies were identified.

All of the included studies were assessed as having a low risk of bias except Peurala et al. [14] which was assessed as having moderate to high risk of bias (Table 2). In Peurala et al. [14], there were no independent observers involved (the same therapists that provided the therapy also evaluated content and duration), the data collection methods were not adequately described, and the data collection instrument was not validated. Furthermore, it was unclear if the study purpose was concealed from the participants and therapists, thereby increasing the risk of overestimation of activity levels.

All the included studies were observational except Peurala et al. [14], which was an RCT. The majority of the included studies were conducted in Australia (Table 3). Five of the included studies were carried out in inpatient rehabilitation facilities and two in acute care hospitals (Table 3). The average time since stroke ranged from 5.6 [15] to 161 [16] days (Table 3). Video recording, behavioural mapping, and contemporaneous recording by the researchers or therapists were the three main methods of observation used in the included studies. In the video recording method of observation, the entire physiotherapy session was video-recorded and later analysed to extract the data. In the behavioural mapping method of observation, the total observation period (for, e.g., from 9 am to 5 pm) is

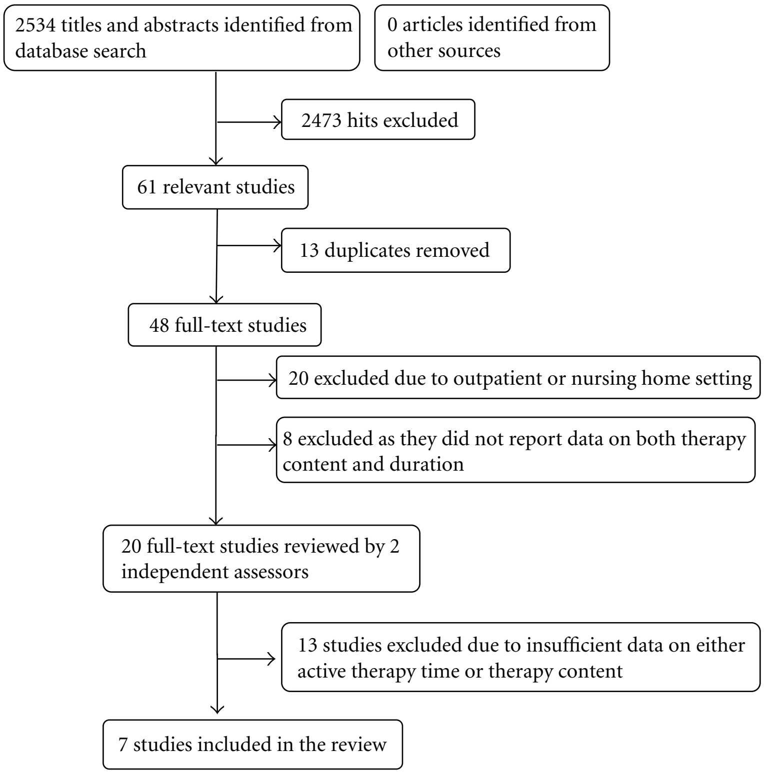

Figure 1: Flowchart of study selection (according to the Prisma statement [13]).

divided into 10-minute time slots. During every 10 minute-time slot, participants are observed for one minute, and their behaviour is recorded. The contemporaneous recording involves researchers or treating therapists recording the content and duration of the therapy sessions in a data collection instrument during or after the observed therapy session.

The mean total therapy session time ranged from 24 minutes to 64 minutes (mean of 49.5 minutes) except Lang et al. [17] (Table 3). Lang et al. [17] measured the number of repetitions performed by participants during a therapy session but they did not report total therapy time. The amount of active time within physiotherapy sessions ranged from 27 minutes to 39 minutes (mean of 32.8 minutes). The percentage of time spent active during a therapy session ranged from 42 percent to 71 percent (mean of 60 percent) (Table 3). The time spent by people with stroke engaged in various physical activity subcategories is outlined in Table 4.

The descriptions of physical activity subcategories and inactivity across the studies varied, but could be collated into categories of walking, standing activities, cycling, transfers (including sit-to-stand), sitting activities, upper limb activities, bed mobility/activities in lying, and inactivity/rest time.

3.1. Walking Practice. The average amount of time spent in walking practice ranged from four to 14.7 minutes per therapy session (Table 4). Walking practice included early gait activities (walking on level surface, therapist assisted using a gait aid) and advanced gait activities (walking on uneven surface, stairs, obstacle courses, and treadmill) [14–16]. In the study by Lang et al. [17], the average number of steps taken per therapy session was 395, and the average number of times the participants got up to walk was nine per therapy session.

3.2. Sitting Activities. All the studies except Lang et al. [17] reported the amount of time spent in sitting activities specifically. Sitting activities included postural control exercises, reaching, and active lower limb exercises. The average amount of time spent in sitting practice ranged from 0.3 to 9.6 minutes.

3.3. Standing Activities. All the studies except Lang et al. [17] reported the amount of time spent in standing activities specifically. Exercises in standing included standing up, shifting weight from one leg to the other, and reaching in standing. The average amount of time spent in standing practice ranged from four to 11.6 minutes per therapy session.

3.4. Upper Limb Activities. All the included studies except De Wit et al. [18] reported the amount of time spent in upper limb activities during therapy sessions. Upper limb activities included active task practice using the paretic upper limb. The average amount of time spent in upper limb activities ranged from 0.9 to 7.9 minutes per therapy session. Lang et al. [17] reported an average of 86 repetitions of active upper limb activities performed per therapy session.

Table 2: Critical appraisal of the included studies.

	Elson et al. (2009) [5]	Lang et al. (2009) [16]	Bernhardt et al. (2007) [14]	Peurala et al. (2007) [13]	DeWit et al. (2006) [17]	Kuys et al. (2006) [15]	Ada et al. (1999) [18]
Study population well reported?	+	+	+	+	+	+	+
Inclusion and exclusion criteria definitively outlined?	+	+	+	+	+	+	–
Adequate sample size?	+	+	+	?	+	+	?
Data collection methods clearly described?	+	+	+	–	+	+	+
Data collection instrument validated?	+	+	+	–	+	+	+
Independent observer involved?	+	+	?	–	–	+	+
Appropriate statistical analysis and its interpretation?	+	+	+	+	+	–	+
Is subset analysis a major, rather than minor, focus of the article?	+	+	+	–	–	–	+
Study purpose concealed from participants	+	+	+	?	?	?	+

Key:

+ Yes – No ? Unclear

3.5. Bed Mobility/Activities in Lying. Only three studies [5, 15, 16] reported the average amount of time spent per therapy session performing bed mobility/activities in lying, this ranged from 0.3 to 5.2 minutes. Bed mobility/activities in lying included rolling, bridging, lying down from sitting, moving across the bed, sitting from lying, and isolated hip/knee control.

3.6. Transfers Including Sit-to-Stand Practice. Five of the included studies [5, 14, 15, 17, 19] reported the amount of time/repetitions spent engaged in transfer exercises per therapy session. Transfers included sit-to-stand, moving from wheelchair to bed, and wheelchair to toilet. The average amount of time spent in transfer practice ranged from 1.8 to 3.7 minutes per therapy session. An average of 11 repetitions of transfers per session was reported by Lang et al. [17].

3.7. Other Therapeutic Activities. Only four of the included studies [5, 14, 18, 19] reported the time spent in other activities. Other therapeutic activities included cycling, activities in kneeling, passive movements, soft tissue techniques, tonus inhibition, positioning to stretch muscles, exercising the affected lower limb in any position, selective movements including coordination, strengthening exercises, and active relaxation. The average amount of time spent engaged in other activities ranged from 4.1 to 16 minutes.

Table 3: Summary of the included studies and their findings in relation to therapy duration.

Author/year	Setting	Location	Mean (SD) time since stroke (days)	Number of participants/therapy sessions		Method of observation	Mean total therapy time per therapy session (mins)	Mean active time per therapy session (mins)	Mean % active time per therapy session
				Participants	Therapy sessions				
Elson et al. 2009 [5]	Inpatient rehabilitation	Australia	47.3 (30.6)	15	30	Video recording	42 CCT: 53 IT: 31	30 CCT: 37 IT: 30	71 CCT: 71 IT: 72
Lang et al. 2009 [17]	Inpatient rehabilitation	USA and Canada	118 (157)	100	312	Recording of number of repetitions of tasks or movements by researchers	NR	36¥	NR
Bernhardt et al. 2007 [15]	Acute hospital	Australia	5.6 (NR)	58	84	Behavioural mapping	24	NR	NR
Peurala et al. 2007 [14]	Acute hospital	Finland	8.0 (3.3)	19	NR	Contemporaneous recording by therapists	55	NR	NR
De Wit et al. 2006 [18]	Inpatient rehabilitation	Europe*	NR	30	60	Video recording	60	39€	65
Kuys et al. 2006 [16]	Inpatient rehabilitation	Australia	161 (405)	30	NR	Video recording	52	32	62
Ada et al. 1999 [19]	Inpatient rehabilitation	Australia	46.9 (52.9)	16	NR	Behavioural mapping	64	27	42

Key: ¥ average amount of time in which the repetitions were observed in a therapy session. Total therapy session including the rest breaks was not provided.
*UK, Belgium, Germany, and Switzerland.
€mean amount of active time in an hour session.
NR: not reported or not able to be extracted from published data, SD: standard deviation, CCT: circuit class therapy, IT: individual therapy, and USA: United States of America.

Table 4: The average amount of time spent by people with stroke engaged in different physical activity subcategories and time spent inactive in therapy sessions.

Author/year	Walking practice	Sitting exercises	Standing exercises	Upper limb activities	Bed mobility/activities in lying	Transfers and sit-to-stand practice	Other therapeutic activities€	Inactive time
Elson et al. 2009 [5]	10.8	0.8	8.5	0.9	0.3	2.7	5.0	12.7
Bernhardt et al. 2007 [15]	4.7	5.7	4.0	2.8	2.8	1.8	NR	NR
Peurala et al. 2007 [14]	14.7	9.6	10.4	1.2	NR	3.7	14.5	NR
De Wit et al. 2006 [18]	6.4	8.4	7.6	NR	NR	NR	16.0	NR
Kuys et al. 2006 [16]	11.8	2.1	11.6	2.9	5.2	NR	NR	12.4
Ada et al. 1999 [19]	4.0	0.3	7.5	7.9	NR	3.2	4.1	37

Key: NR: not reported.
€other therapeutic activities included cycling, activities in kneeling, passive movements, tonus inhibition, positioning to stretch muscles, exercising the affected lower limb in any position, selective movements including coordination, strengthening exercises, and active relaxation.
Total active time after adding up the time spent in each activity subcategory might not be the same as Table 3 due to rounding, and/or inaccuracy of data reported in the included studies.
The data from Lang et al. [17] included the number of repetitions of various physical activity subcategories, and, therefore, was not included in this table.

3.8. Inactive/Rest Time. Only three studies [5, 16, 19] investigated the amount of inactive time during therapy sessions. The inactive periods included time spent resting between activities, receiving instruction from or waiting for the therapist, and use of the nonparetic upper limb/lower limb. The average amount of inactive time ranged from 12.4 to 37 minutes per therapy session.

Figure 2 provides a visual representation of the average amount of time spent engaged in each category of activity in the context of total therapy time and enables a comparison with inactive or rest time.

4. Discussion

This systematic review found that people with stroke spent more than a third (40 percent) of their physiotherapy sessions inactive. In other words, 60 percent of the total therapy session duration was the averaged total active time. Physiotherapy techniques like passive movement, tonus inhibition, and stretching were included in "other therapeutic activities" within active time; therefore, this figure of 40 percent constitutes absolute rest or inactive time. Inconsistencies were found in how others have categorised these techniques as either passive or active, so the most conservative interpretation was chosen. The mean amount of active time in physiotherapy sessions was 32.8 minutes. The most common physical activities observed during physiotherapy sessions were walking, sitting, and standing practice. However, the actual amount of time spent by people with stroke engaged in these activities per therapy session was small (mean of 8.7 (SD 4.3) minutes walking practice, 4.5 (4.0) minutes sitting practice, and 8.3 (2.6) minutes standing practice).

Even less time was spent per therapy session on activities such as upper limb practice, transfers, and bed mobility. While we do not yet know what the optimal dose of therapy time and repetitions is to optimise functional recovery after stroke, neuroplasticity literature suggests that hundreds to thousands of repetitions of a task or movement are required to lead to lasting neural changes [20–23]. This raises the question as to whether the amount of task-specific practice currently provided during stroke rehabilitation is adequate to drive neuroplastic changes for optimal functional recovery.

Overall, the quality of the included studies was moderate-to-high with the exception of Peurala et al. [14] in which the method of data collection was not clearly described or validated. The study relied on therapists recording of the content of physiotherapy sessions which may not be accurate. Therapists are known to systematically overestimate the time participants spend in therapy sessions [24]. We recently completed a study examining the accuracy of physiotherapists in estimating both therapy duration and the time spent in different categories of activity and inactivity in therapy sessions and found therapists systematically overestimated active time by 28 percent and systematically underestimated inactive time by 36 percent (unpublished data). This suggests any studies relying on therapist reports of therapy sessions are likely to overestimate active time. All other studies in the review used more objective measures of estimating active time in physiotherapy sessions. Two studies [15, 19] used behavioural mapping—a well established method by which participants are observed for one minute out of every 10 minutes per day and their activities are recorded. This method poses some limitations as the participants were observed for only one minute out of every 10 minutes during the total observation period. All other studies used some form of continuous monitoring of physiotherapy sessions—either by videoing sessions in their entirety and analysing the footage later [5, 16, 18] or by counting repetitions of a particular task [17]. While these methods are likely to provide a more accurate picture of therapy time, there remains a risk of bias due to a possible increase in activity levels of participants because they are obviously being observed throughout their therapy session. These limitations in study design are most likely to lead to an inflation of active time in physiotherapy sessions.

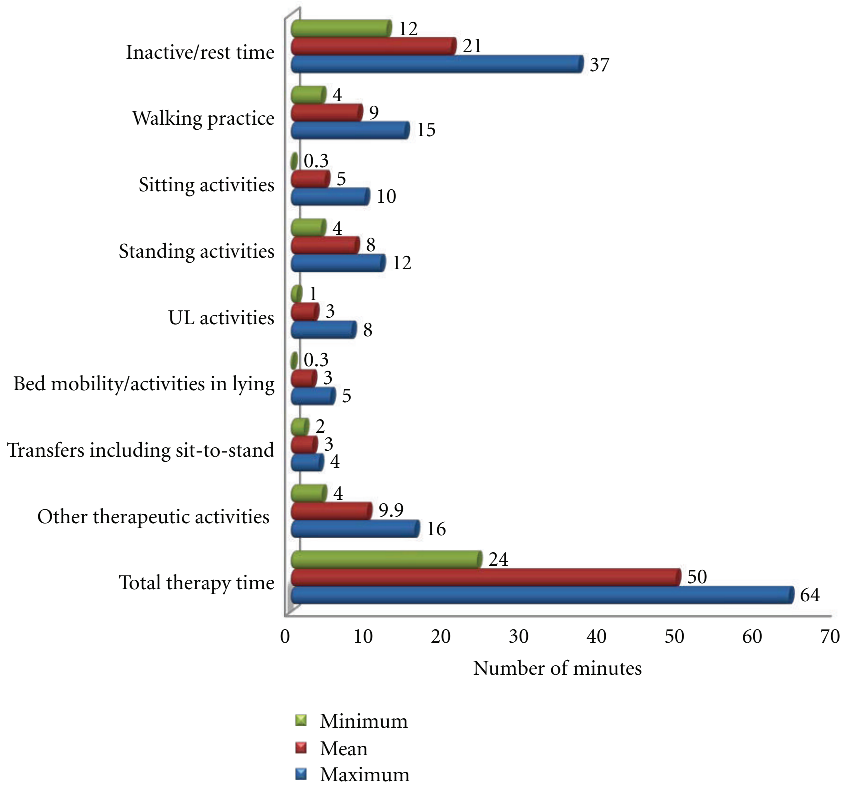

Figure 2: Mean amount of time spent in different physical activity subcategories, and the time spent inactive in relation to the mean total therapy time. The minimum and maximum time spent in different physical activities may not be identical to the data in Table 4 due to rounding.

Two of the included studies were conducted in acute settings and five in inpatient settings. The studies from outpatients and community settings were excluded because frequency and occasions of service delivery would be even more varied and therefore skew the results. Therefore, the findings of this review can only be generalised to services where the person is an inpatient. Even then there are some possible minor differences between acute and subacute settings in terms of length of therapy session provided. For this reason, we have concentrated on the percentage times spent active so that results can be more meaningfully interpreted.

The low level of physical activity within physiotherapy sessions is of concern, considering that clinical guidelines suggest that rehabilitation after stroke should be structured to provide practice time as much as possible, and that at least one hour per day should be spent in active task practice [11]. This review suggests that stroke survivors are doing only around 33 minutes of active task practice in each therapy session which falls well short of the recommended target if it is the only session provided during the day.

The included studies did not report therapy session frequency per day. Therefore, only findings for percentage of total active time per therapy session were summarised. It is possible, particularly in the acute setting, that participants received multiple therapy sessions per day. Further studies are needed to report total active time in therapy sessions for the entire day in line with current stroke guidelines.

Time spent physically active could be increased by increasing the total time spent by people with stroke in therapy sessions. Group circuit class therapy sessions are an alternative to individual physiotherapy sessions. They are longer in duration and therefore have the potential to increase active practice time. Elson et al. [5] reported that the time spent physically active by people with stroke was higher during circuit class therapy sessions due to their longer therapy duration. However, in percentage terms, the time spent by stroke participants engaged in physical activity during circuit class therapy sessions was similar to that of the individual therapy sessions [5]. Therefore, the effectiveness of circuit class therapy sessions in increasing physical activity levels of people with stroke requires further research.

There is a lack of evidence on the optimal dose and timing of therapy (block activity or frequent short bursts) required to enhance functional recovery after stroke. The optimal ways to schedule and deliver therapy is still unknown. However, therapists should aim to maximise the time people with stroke spend physically active in therapy sessions. Further research should focus on investigating the optimum timing and scheduling of therapy sessions.

4.1. Limitations. Only one person completed the first review of titles and abstracts which may have resulted in some potential papers being missed. Data on therapy content and duration could not be directly extracted from some studies [19] and required a process of extrapolation which may have introduced errors. The degree to which the data presented in the included studies is reflective of usual practice is not known. Finally, only data for physiotherapy sessions were located. Studies investigating physical activity time in other rehabilitation sessions (such as occupational therapy) should be conducted to give a more comprehensive picture of the person's overall therapy experience.

5. Conclusion

The findings of this systematic review suggest that people with stroke are engaged in physical activity for less than two-thirds of the total physiotherapy session duration. The time spent by people with stroke engaged in the most commonly observed physical activity categories (walking, sitting, and standing) may be lower than what is recommended, and that is reported to be required to drive positive neuroplastic changes and optimise functional recovery. Therefore, therapists should be aware of the likelihood that people with stroke might not be receiving enough practice time. Researchers need to investigate the optimal therapy intensity and timing of therapy to drive positive neuroplasticity and functional recovery after stroke.

Appendix

Modified Evidence-Based Learning Critical Appraisal Checklist

(i) Is the study population well reported? (i.e., acuity, and severity of stroke)

(ii) Are the inclusion and exclusion criteria definitively outlined?

(iii) Is the sample large enough for sufficiently precise estimates?

(iv) Are data collection methods clearly described?

(v) Is the data collection instrument validated?

(vi) Were those involved in data collection not involved in delivering a service to the target population?

(vii) Is the statistical analysis and its interpretation appropriate?

(viii) Is the subset analysis a major, rather than a minor, focus of the paper?

(ix) Was the study purpose concealed from the participants?

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Clinical Study

Slowing of Motor Imagery after a Right Hemispheric Stroke

Francine Malouin,[1] Carol L. Richards,[1] and Anne Durand[2]

[1] *Department of Rehabilitation, Laval University and Center for Interdisciplinary Research in Rehabilitation and Social Integration (CIRRIS), IRDPQ 525 Boulevard Hamel East, Quebec City, QC, Canada G1M 2S8*
[2] *Institut de Réadaptation en Déficience Physique de Québec, 525 Boulevard Hamel East, Quebec City, QC, Canada G1M 2S8*

Correspondence should be addressed to Francine Malouin, francine.malouin@rea.ulaval.ca

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The temporal congruence between real and imagined movements is not always preserved after stroke. We investigated the dependence of temporal incongruence on the side of the hemispheric lesion and its link with working memory deficits. Thirty-seven persons with a chronic stroke after a right or left hemispheric lesion (RHL : $n = 19$; LHL : $n = 18$) and 32 age-matched healthy persons (CTL) were administered a motor imagery questionnaire, mental chronometry and working memory tests. In contrast to persons in the CTL group and LHL subgroup, persons with a RHL had longer movement times during the imagination than the physical execution of stepping movements on both sides, indicating a reduced ability to predict movement duration (temporal incongruence). While motor imagery vividness was good in both subgroups, the RHL group had greater visuospatial working memory deficits. The bilateral slowing of stepping movements in the RHL group indicates that temporal congruence during motor imagery is impaired after a right hemispheric stroke and is also associated with greater visuospatial working memory deficits. Findings emphasize the need to use mental chronometry to control for movement representation during motor imagery training and may indicate that mental practice through motor imagery will have limitations in patients with a right hemispheric stroke.

1. Introduction

Motor imagery, which is the imagining of actions without their execution, can be defined as an active process during which the representation of a specific action is internally reproduced within working memory without any overt output [1]. The rationale for using motor imagery in the rehabilitation of motor impairments likely arises from the functional correlates that motor imagery shares with the execution of physical movement. For instance, the duration of imagined movements correlates with the duration of real movements [2, 3], simulation of movements evokes similar autonomic responses [4, 5], and, more importantly, the imagination of an action engages largely similar neural networks as its physical execution, notably motor and premotor areas and parietal cortices [6–8]. These observations suggest that real and covert movements during motor imagery obey similar principles and share similar mechanisms.

Temporal characteristics of motor imagery have been extensively studied with mental chronometry in healthy individuals [9]. Studies that examined the temporal relationship between the physical execution of a motor task (i.e., writing, walking, pointing, stepping) and the imagination of the same task (mental chronometry) have found that the imagination and execution times are generally similar (temporal congruence or functional equivalence). In addition, it has been shown that Fitt's law, which states that more difficult movements take more time to produce physically than easier ones, applies also to imagined movements [3] indicating that the timing of movements, either performed physically or imagined, is subject to common laws and principles [10]. For this reason, mental chronometry has been used by many to examine the effects of brain lesions on the temporal organization of motor imagery [11–16], to assess MI ability [9, 17, 18] and to control whether patients are engaged in mental rehearsal during mental practice [19].

While some studies have shown that, following a unilateral lesion of the motor cortex, movements are slower on the affected limbs during both the physical execution and mental simulation of the same movement confirming temporal congruence [11, 12], others have reported that patients with lesions restricted to the superior regions of the parietal cortex could not predict through mental imagery the time necessary to perform various finger movements and visually guided pointing gestures, suggesting that the parietal cortex is important for the ability to generate mental movement representations [13]. More recently, temporal incongruence has been described following stroke during motor imagery of upper limb [14–16] and lower limb [14] movements. In these studies, in contrast to control subjects, patients showed simulation times that were longer than real movement times (overestimation of movement duration) indicative of a slowing of the motor imagery process, especially in persons with right hemispheric (RH) strokes [15, 16]. In the six patients with RH stroke showing a slowing of motor imagery, the corticomotor excitability, as measured with transcranial magnetic stimulation, was not increased during imagery conditions [16] suggesting that facilitation of motor cortex excitability during motor imagery depends on input from regions of the right hemisphere which can be disrupted by right hemispheric stroke.

Because in prior studies limb dominance of the patients was not controlled [14–16] and the number of patients with a right and a left hemispheric lesion was small [15, 16] or uneven [14], no definite conclusion can be drawn as to the impact of the lesion side on temporal incongruence between real and imagined movements. The present study sought to extend these prior findings in a larger sample of patients with right and left hemispheric stroke having similar limb dominance. In addition, since motor imagery is an active process during which the representation of a specific action is internally reproduced within working memory [1] and given the role of the right cerebral hemisphere in image generation [20] and visuospatial working memory [21, 22], we also examined whether lesion side had an impact on visuospatial working memory performance. It was hypothesized that right hemispheric lesions (RHLs) would be associated with both a slowing of motor imagery and greater visuospatial working memory deficits. The aims of this study were to determine whether the slowing of motor imagery after stroke is linked to the side of the cerebral lesion and, further, if it is associated with an impairment of visuospatial short-term memory.

2. Methods

2.1. Participants and Design. The study included a group of 37 persons who sustained a cortical or a subcortical lesion (CVA group) of the right ($n = 19$) or the left ($n = 18$) hemisphere and a group of 32 age-matched healthy individuals (CTL group). To be included in the CVA group, subjects had to present a hemiparesis consecutive to a stroke and be right handed. The patients with the following conditions were excluded: (1) lesions in the cerebellum or midbrain (MRI or CT scan); (2) severe aphasia, based on the clinical evaluation of the speech therapist; (3) severe perceptual problems (i.e., hemineglect) discerned by clinical tests performed by the treating occupational therapist and severe cognitive impairments determined by the neuropsychologist evaluation; (4) other neurological conditions (i.e., Parkinson's disease, dementia). To be included in the CTL group subjects had to be between 35 and 80 years old, without physical or cognitive impairments. All subjects gave informed, written consent for their participation in the study and the protocol was approved by the Ethics Committee of the Rehabilitation Institute where the study took place.

2.2. Assessment Procedures. Prior to the administration of the chronometric tests, the hand and leg dominance were assessed using reliable measures of hand and foot preference [23, 24]. Prior to formal chronometric testing, motor imagery vividness was assessed using the Kinesthetic and Visual Imagery Questionnaire, a reliable and valid assessment tool for persons with physical disability [17, 25]. This was followed by a chronometric test that compares the movement times during the imagination and execution of the stepping task [17, 18]. In this stepping task the subject is seated rather than standing [14] because stepping movements in sitting are easier for persons with severe motor and balance impairments. This stepping task in sitting involves hip flexion to lift the foot off the floor and knee extension-flexion to place the foot on the target and then to return it to the starting position. Thus, subjects sitting on a chair with a backrest with both feet resting on the floor were asked to imagine (I) and then execute physically (E) two series of five stepping movements. The movements consisted of placing one foot forward onto a board (target) and then returning it to the floor. The board (41 cm wide × 26 cm long × 2 cm high) was placed transversely about 5 cm in front of the feet. The test-retest reliability of this chronometric test has been confirmed in 20 persons with stroke and 46 age-matched healthy controls [18]. During testing, subjects were required to close their eyes and to verbally signal each time they imagined touching the target. To promote motor imagery (internal perspective or first-person perspective), they were instructed to see and feel moving their leg from the inside (i.e., as if they were really doing it and not watching from the outside like looking in a mirror) until the examiner told them to stop. Two series of five stepping movements were carried out with each leg. The imagination condition was presented first to minimize the possibility that the subject was influenced by the duration of the real movement or used a counting strategy. The same procedure was repeated for the second series. Each series and each condition (imagination and execution) were separated by a 30 s rest period. Prior to formal testing, there was a demonstration of the task and a practice run (physical and mental).

Three domains of working memory were assessed: visuospatial, verbal, and kinesthetic. We used a standardized procedure [26] that has been widely used with persons with brain injury [27]. The examiner presents a series of items and asks the subject to reproduce it immediately in the same order. For each domain, items are taken randomly from a limited pool of items and are presented sequentially. For each type of material, 5 lists of 2 items were first presented. If the subject could reproduce correctly 3 of the 5 lists, the list length was increased by 1 item otherwise, testing was interrupted. The verbal stimuli were taken from a set of 9 frequent and imaginable monosyllabic words presented in the auditory modality [28]. In the visuospatial condition, the examiner tapped on a series of 9 blocks (Corsi block-tapping task) presented in a random arrangement in front of the subjects. The subject was asked to reproduce the sequence by tapping on the same blocks [29, 30]. In the kinesthetic condition, the same standardized procedure was used as previously but the stimuli were constructed to test working memory for movement [31, 32]. The examiner produced passively a series of gestures, and the subject (blindfold) was asked to reproduce them. The gestures involved unilateral and bilateral lower-limb movements as well as movements involving the trunk and the upper and lower limbs.

2.3. Data Analysis. The mean duration of the two series of five movement repetitions was averaged for each limb and each condition. Imagination/execution (I/E) time ratios were calculated to quantify the temporal congruence between the two conditions. For working memory tests, the number of sequences and the number of items correctly recalled were converted to percent of maximal possible score and the percent score of the two parameters was averaged [31, 32]. To quantify the degree of temporal coupling (I/E) time ratios were computed [17, 18].

The age among groups was compared with the paired Student's t-test. Because the time after stroke was longer in the RHL subgroup than the LHL subgroup, an analysis of covariance taking into account the time after stroke was carried out with 2 within-subjects factors (limb side and condition) and one between-subjects factors (side of hemispheric lesion). Since there was no significant time interaction, further analyses using analysis of variance (ANOVA) for repeated measures were carried out. For each group (CTL and CVA), an ANOVA for repeated measures for two within-subjects factors: limb side (affected and unaffected) and condition (physical execution and mental simulation), followed by the post hoc Bonferroni procedure was carried out to examine whether temporal congruence was preserved. Then, to determine the effect of the side of the hemispheric lesion on temporal congruence, an ANOVA with repeated measures for two within-subjects factors: limb side (affected and unaffected) and condition (physical execution and mental simulation), and one between-subjects factors (left and right hemispheric lesion) followed by the post hoc Bonferroni procedure were conducted. To establish whether the degree of temporal congruence was comparable after an RHL and LHL, a similar analysis was carried out on the I/E time ratios. Impairment of working memory ability was examined for each dimension between groups (CTL, RHL, LHL) with a one-way ANOVA. The relationship between imagination and execution times was studied with the r Pearson product-moment correlation. The statistical level of significance was set at 0.05. Statistical tests were performed with SPSS 11.0 for Windows.

3. Results

Subject characteristics are reported in Table 1. When available in the medical chart, results from four clinical tests (Timed-Up and Go, gait speed, Fugl-Meyer Sensorimotor Assessment, Balance Scale) are provided to give additional information about motor disability. There were no significant differences between groups for all variables except for the time after stroke which was significantly longer ($P = .01$) in the subgroup of patients with an RHL; however, both groups were in a chronic stage (1 and 2 years after stroke). The visual motor imagery subscores were greater than corresponding kinesthetic imagery scores in all groups ($P = .004$) except in the RHL subgroup that did not show the usual visual motor imagery dominance. The cerebrovascular accidents (CVAs) induced unilateral lesions (cortical and/or subcortical) that were confirmed by CT or MRI scans. The lesions were located in the left ($n = 18$) or the right ($n = 19$) hemisphere resulting in paresis of the contralateral side of the body (Table 2). All patients had right-hand dominance, and all but one patient in each group (Table 2: subject 18R and subject 4L) had right-foot dominance.

Results from the ANOVAs carried out for each group separately (Figure 1(a), left panel) showed that, in the CTL group, there was no significant difference in the movement times between limb side ($F_{(1,31)} = .015$; $P = .903$) and condition ($F_{(1,31)} = 2.249$; $P = .144$) and no interaction ($F_{(1,31)} = .077$; $P = .783$) between limb side and condition indicating a temporal coupling between imagination and execution conditions for both limbs. The temporal congruence between conditions is reflected by I/E time ratios near 1 in the dominant and nondominant limb sides, respectively (mean: 1.09 and 1.10) (Figure 1(a), right panel). In contrast, in the CVA group (RHL and LHL: $n = 37$) movement times were longer on the affected side than on the unaffected limb side (limb side effect: $F_{(1,36)} = 10.6$; $P = .002$), and a significant effect of condition was also observed ($F_{(1,36)} = 22.3$; $P = .0001$) with longer movement times during the imagined condition than the execution condition, but there was no limb side x condition interaction ($F_{(1,36)} = .660$; $P = .44$) (Figure 1(b), left panel). These findings imply that movements are slower on the affected limb side and that for both limbs they are slower during the imagination condition compared to the execution condition indicating a temporal uncoupling between imagination and execution conditions on both limb sides. The degree of temporal uncoupling is reflected in high I/E time ratios on both the affected (mean: 1.23 and 1.34) and unaffected limbs, respectively, indicating that subjects overestimated by 23% and 34% the duration of stepping during the imagination condition (Figure 1(b) right panel).

To determine whether temporal uncoupling was linked to the side of the hemispheric lesion, further analyses comparing the subgroups of patients were carried out. The mean (SD) movement durations are illustrated for each limb side and condition in Figure 2(a). Results from the ANOVAs revealed a significant effect of limb side ($F_{(1,35)} = 10.36$; $P = .003$) and condition ($F_{(1,35)} = 23.94$; $P = .0001$) as well as a group x condition interaction ($F_{(1,35)} = 4.67$; $P = .037$).

Table 1: Subject characteristics.

	CTL ($n = 32$)	CVA ($n = 37$)	RHL ($n = 19$)	LHL ($n = 18$)
Age (y)				
Mean	59.0	60.1	61.5	58.5
SD	10.6	8.0	8.8	7.0
Range	37.6–77.6	47.2–75.0	48.1–75.0	47.2–72.1
Gender				
Men	14	27	15	12
Women	18	10	4	6
Time since onset (mo)				
Mean	NA	24.0	34.4*	13.0
SD		26.8	32.1	13.2
Range		1.8–123.8	1.8–123.8	2.1–44.0
KVIQ: visual (50)				
Mean	36.9**	38**	37.3	39.4**
SD	8	7.8	7.9	7.8
Range	15–49	16–50	16–50	25–50
KVIQ: kinesthetic (50)				
Mean	32.2	34	34.8	34.1
SD	8.6	9.7	10	9
Range	15–48	12–50	12–49	17–50
Gait speed (cm/s)		($n = 36$)	($n = 18$)	($n = 18$)
Mean	NA	85.2	77.9	92.4
SD		36.4	35.0	37.2
Range		9.7–162	9.7–133.7	33.5–162
Timed up and go (s)		($n = 29$)	($n = 14$)	($n = 15$)
Mean	NA	20.4	25.0	16.1
SD		15.2	19.7	7.8
Range		7.3–83	8.4–83	7.3–34.0
Balance scale (56)		($n = 35$)	($n = 18$)	($n = 17$)
Mean	NA	49.7	47.7	51.8
SD		8.4	9.6	6.6
Range		23–56	23–56	31–56
Fugl-Meyer (34)		($n = 28$)	($n = 14$)	($n = 14$)
Mean	NA	26.7	28.1	25.3
SD		6.5	5.8	7.0
Range		11–34	16–34	11–33

*Longer ($P = .01$) time after stroke in the RHL group; **higher visual than kinesthetic scores within group ($P = .004$); KVIQ: Kinesthetic and Visual Imagery Questionnaire; Fugl-Meyer Sensorimotor Assessment: motor subscore of the lower limb, Max value in brackets; NA: not applicable.

Post hoc analyses indicated that, in contrast to the LHL subgroup, in the RHL subgroup the movement times on both the affected and unaffected limb sides were longer during imagination ($P = .0001$) than during execution, reflecting a bilateral temporal uncoupling. The degree of temporal uncoupling as revealed by I/E time ratios are illustrated in Figure 2(b). Results from the ANOVAs revealed a significant group ($F_{(1,35)} = 6.99$; $P = .01$) and limb side effect ($F_{(1,35)} = 4.04$; $P = .05$) but no interaction ($F_{(1,35)} = .108$; $P = .744$). The findings also indicate that I/E time ratios in the RHL subgroup on both the affected limb (1.37; $P = .01$) and the unaffected limb (1.50; $P = .01$) were higher than corresponding I/E time ratios in the LHL subgroup (1.09 and 1.12). Thus, subjects with an RHL were overestimated by 37% and 50% the duration of stepping movements during the imagination condition, compared to 9% and 12% in the LHL group. Figure 3 provides individual I/E time ratios for each subgroup arranged in an ascending order (subject numbers do not match those in Table 2) and the graphs illustrate the variability between patients. In each subgroup, some take more time to imagine than to execute stepping (ratio above 1 = overestimation) others take less time (ratio below 1 = underestimation). Note that while in the LHL subgroup, I/E time ratios on affected and unaffected limb

Table 2: Lesion location.

Right hemispheric lesion ($n = 19$)				Left hemispheric lesion ($n = 18$)			
N	Lesion location	I/E time ratio		N	Lesion location	I/E time ratio	
		Aff.	Unaff.			Aff.	Unaff.
1R	MCA territory	0.82	1.79	1L	MCA territory	0.69	0.85
2R	Frontoparietal cortex	0.95	0.79	2L	MCA territory	0.72	0.94
3R	Internal capsule, basal ganglia, and corona radiate	0.96	1.55	3L	Internal capsule (post. limb)	0.79	1.04
4R	Frontal (post.) and temporal cortex	0.96	1.19	4L	Frontal cortex (post.) and subcortex	0.83	1.03
5R	MCA territory	1.08	1.36	5L	MCA territory	0.85	0.90
6R	External capsule and basal ganglia	1.10	1.05	6L	MCA territory	0.98	0.89
7R	MCA territory and thalamus	1.12	1.05	7L	Frontoparietal cortex and basal ganglia	1.00	0.96
8R	MCA territory	1.14	1.21	8L	Frontal cortex (post.)	1.03	1.14
9R	Frontoparietal (subcortical)	1.24	1.27	9L	Thalamocapsular	1.10	1.20
10R	MCA territory	1.26	1.38	10L	Parietotemporal cortex	1.27	1.32
11R	MCA territory	1.30	1.54	11L	Parietal cortex	1.28	1.15
12R	Internal capsule and corona radiate	1.31	1.33	12L	Frontal cortex and subcortex	1.52	1.34
13R	Temporolenticular	1.46	1.63	13L	Frontotemporal cortex and putamen	1.53	1.64
14R	MCA territory	1.49	1.48	14L	Frontal cortex (post.), caudate nucleus	1.10	1.31
15R	Frontoparietal cortex	1.58	0.98	15L	Paraventricular from claustrum to external capsule	1.40	1.55
16R	MCA territory	1.54	2.67	16L	Frontal cortex and intraventricular	1.22	1.31
17R	MCA territory	1.76	1.76	17L	Subcortex paraventricular	1.07	1.11
18R	MCA territory	2.27	2.68	18L	Temporooccipital cortex	1.19	1.48
19R	MCA territory	2.53	1.70				

N: patient number; I/E time ratio: imagination/execution time ratio; MCA: middle cerebral artery; aff.: affected limb; unaff.: unaffected limb.

sides were generally similar and were close to 1, those in the RHL subgroup tended to differ more between limb sides with several values above 1.5. The latter difference between limb sides is reflected in the correlation coefficients of $r = .86$ and $r = .56$ computed between I/E ratios of the affected and unaffected limbs in the LHL and RHL subgroups, respectively.

Figure 4 illustrates the mean (1SD) visuospatial, kinesthetic, and verbal working memory performance for the subgroups of patients with a left (LHL) and a right (RHL) hemispheric lesion and for the control subjects (CTL). Results from the ANOVA indicate a significant decrease in performance for the visuospatial domain after an RHL ($P = .006$) and a significant decrease in the kinesthetic domain after an LHL ($P = .006$), while both subgroups had a significant deficit in the verbal domain (LHL: $P = .000$ and RHL: $P = .002$). A near significant ($P = .06$) correlation was found between visual working memory and the I/E time ratio for the unaffected leg ($r = .25$) for the whole group ($n = 37$); when individually examined, however, the correlation was stronger ($r = .35$) in the RHL subgroup than the LHL subgroup ($r = .20$) but did not reach statistical significance.

4. Discussion

The results indicate that patients with an RHL demonstrated temporal incongruence between real and imagined stepping movements. In contrast to CTL individuals and patients with an LHL, in the RHL group the imagination times during the imagination of stepping movements on the affected and unaffected side were, respectively, 37% and 50% longer than execution times (overestimation) indicating a bilateral slowing of motor imagery. Our findings concur with previous findings [15, 16] describing similar temporal incongruence for upper limb movements in a smaller sample of persons with RHL and thus extend the notion of a temporal deficit of motor imagery to movements of the lower limbs.

With the computation of I/E time ratios it is possible to measure the level and direction (over- or underestimation of imagined movement times) of temporal incongruence which varies between subjects within each group. It is of note that more patients in the RHL group had high ratios above 1 (Figure 3 and Table 2). As shown in Table 2, the cerebral lesions were quite extensive and involved similar regions in

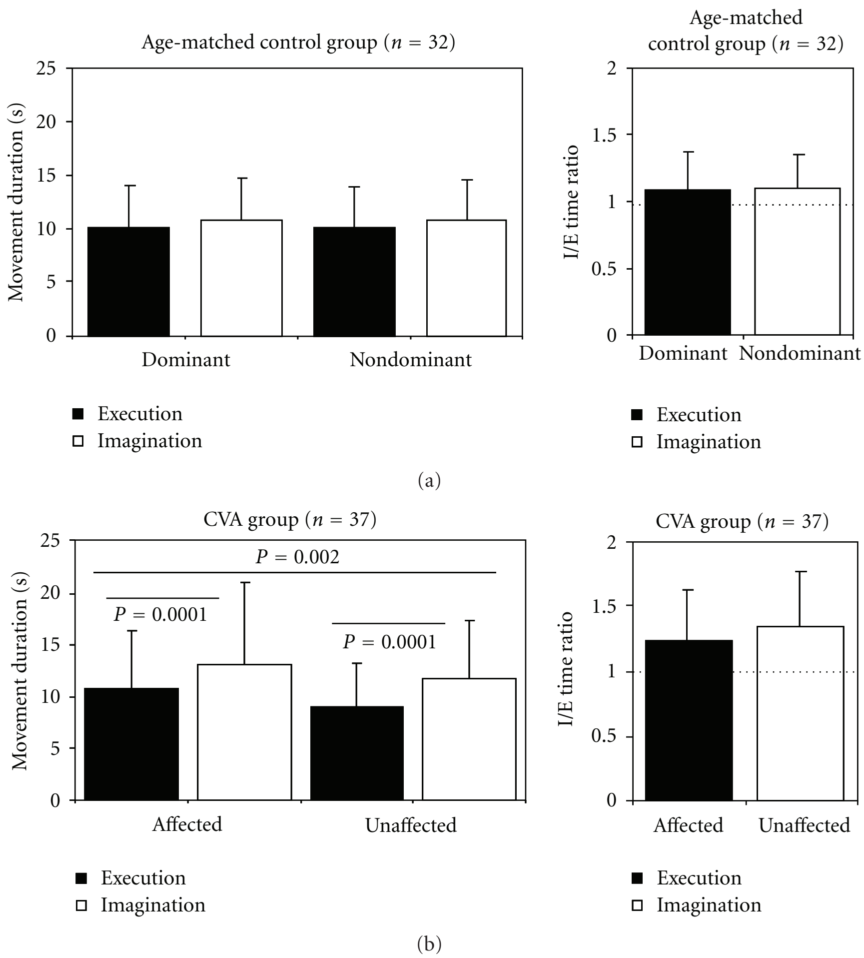

Figure 1: (a) Mean duration (1SD) of stepping movements during physical execution and mental simulation conditions (left panel) and imagination/execution time ratio of dominant and nondominant sides in age-matched healthy individuals. Similar duration during both conditions (temporal equivalence) yielding I/E time ratio near 1. (b) Similar illustration as in (a) for the stroke group. Longer stepping movement times during the imagination compared to the execution condition in individuals with stroke (total group); I/E time ratios above 1 indicating a lack of temporal congruence. Dotted lines indicate temporal congruence of 1 to 1.

both groups, thus making it difficult to associate temporal incongruence with specific regions. However, note that I/E time ratios were highest in RHL patients with lesions located in the middle cerebral artery (MCA) territory. Conversely, MCA territory lesions in the LHL group yielded low I/E time ratios suggesting that lesions of the MCA territory in the right hemisphere damage areas critical to processes underlying motor imagery.

For instance, the extensive lesions may have damaged regions of the RH involved in time-keeping mechanisms. Indeed, Harrington et al. [33] found that duration-perception deficits (overestimation) after RHL were associated with lesions in the premotor and prefrontal cortex known to be critical for working memory (Brodmann areas 6, 8, 9, and 46), and lesions in the inferior parietal cortex essential for movement representation. They also found that, despite the similarity between the RHL and LHL subgroups in lesion loci and size, only RHLs were associated with a disruption in time discriminations [33]. Their results implicate a right hemisphere prefrontal-inferior parietal network in timing and suggest that time-dependent attention and working memory functions may contribute to temporal perception deficits observed after damage to this network [33, 34]. Likewise, the impairment of visuospatial working memory to a greater extent in the RHL could also have resulted from additional damage to the RH which is important for maintaining spatial information over time during motor imagery [21, 22]. Although the visuospatial working memory deficit was greater in the RHL than the LHL subgroup, we could not establish a strong correlation between the level of temporal incongruence as measured by I/E time ratios and working memory deficit. Thus, further studies with a larger sample or a sample with a greater range of deficits would be needed to confirm the link between these factors.

Other examples of motor imagery deficits associated with RHL come from studies in children with cerebral palsy (CP). The study comparing motor imagery accuracy (hand

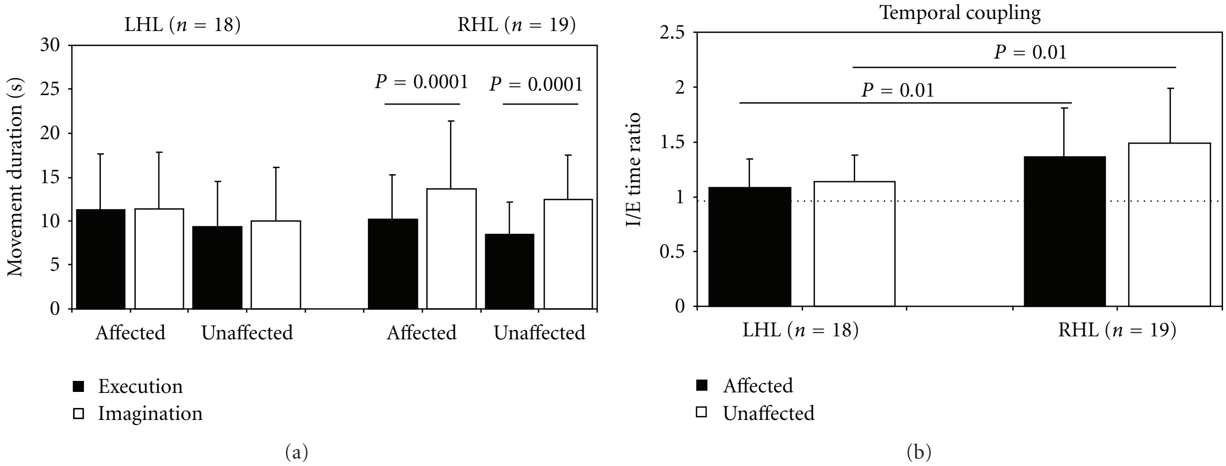

Figure 2: (a) Mean duration (1SD) of stepping movements during physical execution and mental simulation conditions on affected and unaffected sides in the subgroups of patients with a left hemispheric (LHL) and a right hemispheric (RHL) lesion. Note that the RHL subgroup, in contrast to the LHL subgroup, had longer movement times during the imagination condition. (b) Corresponding imagination/execution time ratios for dominant and nondominant sides in each subgroup of patients with an LHL or an RHL. Dotted line indicates temporal congruence of 1 to 1.

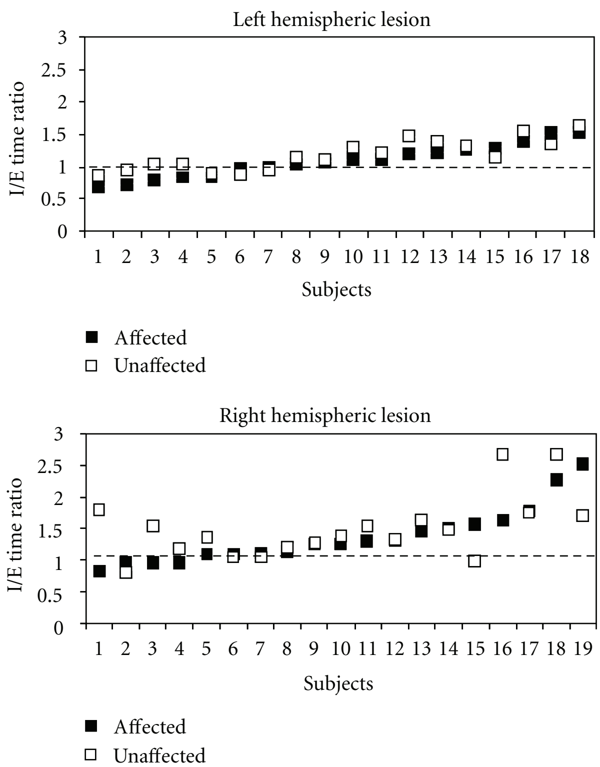

Figure 3: Illustration of individual I/E time ratio for the affected and unaffected sides in each subgroup of patients.

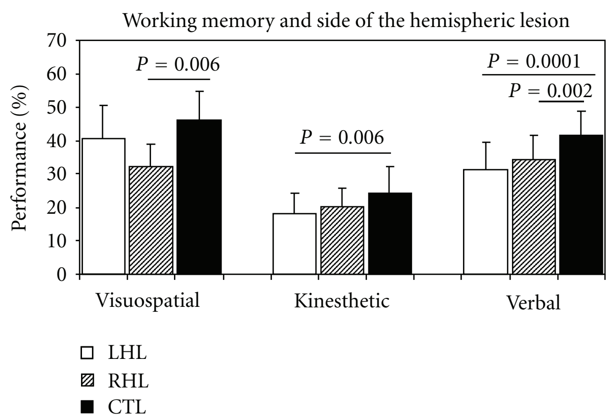

Figure 4: Mean (1SD) visuospatial, kinesthetic and verbal working memory performance for the sub-groups of patients with a left (LHL) and a right (RHL) hemispheric lesion and for the control subjects (CTL).

rotation task) in children with congenital hemiplegia [35] showed that children with an RHL were a little slower and less accurate in a hand rotation task compared to those with an LHL and that this deficit was also correlated with the functional level as measured by the Vineland Adaptive Behavior Scales. Lastly, findings from a recent case study of a young boy with CP affecting the left side of his body provide evidence that children with CP have deficits in tasks involving visuospatial working memory and imagery ability [36] supporting the notion that visuospatial working memory is interconnected with the generation and maintenance of mental images [37–39].

The question arises as to the clinical significance of the slowing of motor imagery after RHL. It does not necessarily imply that patients with an RHL are unable to engage in motor imagery, but it does put into question the interpretation of mental chronometry outcomes. In fact, depending on the motor task or the context of mental practice, the duration of simulated movements can be overestimated (longer duration) or underestimated (shorter duration) even in normal subjects [9]. This means that it is essential to have comparative data from healthy subjects (especially for complex tasks) to control for these normal temporal variations. In the present study, normal subjects demonstrated temporal congruence for stepping movements, concurring with earlier findings for simple or highly automatic movements such as walking and grasping [9]. However, imagination times have been shown to increase up to 30% with task difficulty in healthy individuals [2, 9, 10]. Based on these observations, the overestimation of duration during imagined stepping after an RHL could indicate that the simulation of a simple motor task becomes more demanding after an RHL. In fact, although both subgroups had a good level of motor imagery vividness, the RHL group did not show the usual visual motor imagery dominance likely indicating that the generation of vivid images of the task was not as successful.

Mental chronometry is a simple tool that should be used on a regular basis to monitor the capacity of patients to reproduce mental tasks during motor imagery practice, especially for complex tasks with several sequences of movements such as activities of daily living (i.e., reaching for a glass and drinking, use of utensils, combing hair, eating, turning pages). This is important because in a recent study it was found that the imagination times could be 2 to 3 times shorter than execution times suggesting that the patients were not successfully engaged in mental rehearsal or did not understand the instructions [40]. Such underestimation of simulated movements may indicate some difficulty in representing mentally the task accurately as this has been documented in less experienced athletes for more complex tasks (i.e., skydiving and springboard diving), or when they rehearsed only one phase of complex movements [41, 42]. Thus, temporal incongruence should alert us as to whether a person has problems in movement representation or to comply with the instructions. It is also important to take into account the factors (i.e., task, context, experience) that normally influence temporal congruence. Lastly, based on present results severe temporal incongruence may indicate that the use of mental practice through motor imagery will have limitations in patients with a right hemisphere stroke.

In comparison to the control group, both subgroups of patients showed a decline in verbal working memory which should not be surprising since imaging studies [43, 44] have demonstrated that bilateral parietal regions are engaged when verbal information has to be recalled from short-term memory [45]. On the other hand, the greater working memory deficit in the kinesthetic domain found after LHL is in keeping with the role of the left hemisphere in short-term maintenance of kinesthetic information [46].

Present findings are limited to adults with subacute and chronic ischemic strokes not involving the cerebellum or midbrain and without severe complications such as aphasia, neglect, or apraxia. Moreover, the findings cannot be extrapolated to more complex motor tasks or tasks involving the upper extremities. Also, there was one control subject ten years younger than the youngest patient. However, because the mean and median values were very close in both groups, it should not have too great an impact on the outcomes, especially since the main findings were based on comparisons made between subgroups of patients with similar age range, mean and median values. Another potential limitation is that the two groups of patients were not matched for stroke location and that the lesions were not focalized as in the Harrington et al. study [33]. Lastly, the time since stroke in the RHL subgroup was longer than in the LHL; however, statistical analysis with time after stroke as a covariable did not reveal a significant effect on movement duration and thus time after lesion should not have affected present findings, especially since both groups were in a chronic stage (mean: 12 and mean: 24 months).

5. Conclusion

Although motor imagery vividness is preserved after RHL, patients take more time to imagine than to execute physically stepping movements, indicating that the temporal congruence between real and imagined movement is not maintained. In addition, visuospatial working memory deficits were greater after an RHL than an LHL. Based on the analysis of lesion location and corresponding level of temporal incongruence, it is likely that extensive lesions in the RHL have damaged areas critical to processes underlying motor imagery. Mental chronometry is a simple method easy to use on a regular basis to monitor the capacity of patients to reproduce mentally motor tasks during mental practice. Temporal differences between real and imagined movement times for simple stepping movements, as evidenced here after an RHL, underline the need to use mental chronometry to control for possible temporal aberrations, especially during more complex tasks [41, 42].

Acknowledgments

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Clinical Study

Functional Exercise and Physical Fitness Post Stroke: The Importance of Exercise Maintenance for Motor Control and Physical Fitness after Stroke

Birgitta Langhammer[1] and Birgitta Lindmark[2]

[1] *Physiotherapy Programme, Faculty of Health Sciences, Oslo University College, Box 4, Sanct Olavs pl, 0130 Oslo, Norway*
[2] *Physiotherapy, University Hospital, Department of Neuroscience, Uppsala University, Entrance 15, 751 85 Uppsala, Sweden*

Correspondence should be addressed to Birgitta Langhammer, Birgitta.Langhammer@hioa.no

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It is argued that all stroke patients, indifferent of disability, have the same possibility to improve with training. The aim of the study was to follow and register functional improvements in two groups with different functional capacities at baseline for a period of 36 months. Stroke patients were recruited and divided into groups related to their functional status at baseline. During the acute rehabilitation, both groups received functional task-oriented training, followed by regular self- or therapeutic driven training the first year after stroke and varied exercise patterns the following 24 months. The participants were tested on admission, and at three, six, twelve, and thirty-six months after the onset of stroke. Both groups improved functional activity up to six months which then stabilized up to twelve months to decline somewhat at thirty-six months after stroke. Change scores indicate a greater potential for rehabilitation in the MAS ≤35 in relation to group MAS >35 although the functional capacity was higher in the latter. This indicates the importance of maintaining exercise and training for all persons after stroke.

1. Introduction

Stroke care has undergone major changes in the last 15–20 years in the western world. New treatments, diagnostic tools, and the implementation of stroke units with multidisciplinary rehabilitation are now the golden standard in the acute treatment of stroke and have improved the possibilities for survival and to resume life in the home [1–6]. A major part of the efficacy of the stroke unit is the focus on early mobilization and rehabilitation with task-oriented training which implies the importance of exercise to achieve optimal function. Task-oriented exercise are shown to be most effective to attain optimal motor function and independence in activities in the acute rehabilitation [7, 8]. The importance of exercise and training after stroke has also been documented [9–11]. Studies have shown that persons with stroke, given the opportunity to exercise in the year after stroke, maintain their functional status after the initial rehabilitation and improve function [9–12]. Regular exercises were sustained both with an organised and a voluntary follow-up regimen during the first 12 months after stroke. In the longitudinal randomised controlled trial, both groups received functional task-oriented training tailored according to their specific needs during the acute period of rehabilitation. At discharge from the acute hospital, patients were randomised into different groups. Patients allocated to an organised exercise group were scheduled to have four periods of physiotherapy during the first year after their stroke, with a minimum amount of 80 hours exercise. The exercises were in this group focused on intensive functional endurance, strength, and balance exercises. The patients belonging to the voluntary exercise group were not sent for follow-up treatment on a regular basis but were tested regularly to the same extent as the organised group [10–12]. The result one year after stroke showed that amount and intensity of exercise was high in both groups, with therapeutically steered training in the organised exercise group and self-initiated training in the voluntary exercise group. Frequency of training per week in the organised group was 2.1 times per week and in the voluntary group 2.2 times per week. The patients improved to the same degree in Instrumental Activities of Daily Living and 6-Minute Walk Test, Berg Balance Scale, Timed-Up-and-Go, and grip strength, and without increasing muscle tone. The results also showed that improvements in walking capacity and balance were especially important for increased activities in Instrumental Activities of Daily Living and participation in society. This is in sharp contrast to no physical activity, exercise, or training after stroke where decline of function show is a progressing pattern in motor function and activities of daily living [13]. A reduction of physical fitness and strength has also been reported for persons with stroke in other studies [14–18].

Furthermore, it is argued that all stroke patients, indifferent of disability, have the same possibility to improve with training [19]. On the other hand, no study has had a sole focus on this difference in a stroke population. It is established that the effect of training will be greater in persons with little or poor ability versus the more trained person [20]. However, among persons with stroke, this seems to be reverse, and rehabilitation clinics indicate a slower progress for persons with more severe stroke at onset [21].

These results underline the importance of physical activity, exercise, and training for all persons with stroke, with focus on both capacities in body functions and activities. However, subgroups with minor, moderate, and severe deficits after stroke might possibly have different goals and needs when it comes to type of exercise after stroke. A person with minor stroke might be able to return to the almost the same physical level as before the stroke and may be able to use the different possibilities for physical activities that exist outside the health services. Persons with moderate and major strokes, on the other hand, may have need for adapted physical activities and exercises in order to maintain optimal function. These services are more limited and perhaps not so easily accessed.

The principal aim of the study was to investigate how motor function, balance, mobility, walking capacity, and activity patterns may differ between two groups with different functional capacities at baseline. Another aim was to follow functional improvements during and postrehabilitation in the groups during and after interventions in a 36-month period.

It was hypothesized that there would be a significant difference between the groups in functions but that both groups would improve in all functional activities, inline with current theories. However, it is expected that the functional gains during the rehabilitation and poststroke period would be lower in persons with a major disability at baseline than in those with a moderate to minor disability. Furthermore, it was hypothesized that the first group would be slightly slower in their progress of improvement than the latter.

2. Method

2.1. Subjects. The participants were 75 persons with stroke divided into two groups, according to motor function after stroke. The participants were recruited for an intervention study and a randomized controlled trial, described in other articles [10–12]. Patients with stroke were consecutively screened for inclusion. Inclusion criteria were first time ever stroke with neurological signs and voluntary participation. The information about the intervention study was given in writing and verbally. An informed consent was obtained by methods approved by the Regional Committee of Medical Research Ethics of Norway. The material in this new study has been reanalyzed; groups have been rearranged according to better or poorer motor function as measured with Motor Assessment Scale [22]. Scores ranging from 0 to 35 were considered as having a major functional disability and are hence called MAS group <35 ($n = 37$; after 36 month $n = 27$), and persons with scores from 36 to 48, which indicates a moderate-to-minor disability, are called MAS group >35 ($n = 38$; after 36 months $n = 33$). The division of Motor Assessment Score <35> is significantly correlated to BI <60> ($P = 0.001$, $r = 0.7$) [23]. The score, <60, in Barthel Index has been used as cut score for prediction of placement in a nursing home [24].

2.2. Outcome Measures. A test protocol consisting of the Motor Assessment Scale (MAS) [22], Berg Balance Scale (BBS) [25], Timed Up and Go TUG) [26], 6-Minute Walk Test (6MWT) [27], and the Barthel Index of Activities of Daily Living (BI) [23] was used.

The patients were tested on admission, and at three, twelve, and thirty-six months after the onset of stroke by an experienced investigator, blinded to group allocation. The tests were performed in the general hospital, in the patients' homes, and in community service centres.

The Motor Assessment Scale is a test of motor function developed by Carr et al. [22]. Each item scores from 0 = no function to 6 = normal function. Hence, the total scores of the eight items range between 0 and 48. The test has been shown to have high inter- ($r = 0.89$ to 0.99) and intrareliability ($r = 0.87$ to 0.98), and high construct cross-sectional validity ($r = 0.88$ and $r = 0.96$) [28].

The Barthel Index of Activities of Daily Living is a test of primary activities of daily living (ADL) developed by Mahoney and Barthel [23] for the purpose of measuring functional independence in personal care and mobility. The items are weighted differently. The scores reflect the amount of time and assistance required by a client. A score of 0 (complete dependence), 5, 10, or 15 is assigned to each level, with a possible total score of 100 (totally independent). The test has high scores for inter- ($r = 0.70$ to 0.88), and intrareliability ($r = 0.84$ and $r = 0.98$) and construct cross-sectional validity ($r = 0.73$ to 0.77) [28]. Scores below 60 indicate a need for institutional care [24].

Walking capacity was monitored by the *6-Minute Walk Test*, using a standardised protocol [27]. The 6MWT was performed in an 85 m long corridor in the hospital or different institutions. In patients' homes, this test was preferably performed outdoors on an 85 m long stretch on an even level. Indoors in patients' homes the longest stretch was chosen, but this was done only twice with two patients, 6 and 12 months after stroke. The patients were encouraged to walk as long a distance as they could in 6 minutes (m), and this was registered as well as gait velocity (m/s). The 6MWT is also used to assess exercise tolerance [29, 30], thus measuring functional exercise capacity. Gait velocity has been tested among elderly individuals for validity and reliability, with satisfactory results [28, 31], and it has also been used in several stroke studies [32].

The Berg Balance Scale (BBS) is a balance test consisting of 14 items, scored from 0 = no balance to 4 = full balance [25]. This scale has been found to be especially sensitive for the detection of risks of falls in frail elderly persons. An overall score of less than 45 points, out of a maximum of 56, is associated with a 2.7 times increase in the risk of a future fall [33]. The BBS has been used in many studies and has been tested for reliability and validity with good results [28].

Timed Up and Go (TUG) is a functional mobility test that is used in the clinic to evaluate dynamic balance, gait, and transfers [26]. The patient is asked to get up from a chair (46 cm high), with support for the arms, walk three meters, turn, go back, and sit down. The physiotherapist monitors the time taken from the start to the end, when the patient is seated. The test is valid and reliable for function and transfers indoors for frail elderly and has been used in several studies [26, 28, 31].

2.3. Intervention. During the acute phase of rehabilitation at the hospital, both groups received functional task-oriented training tailored to their specific needs. In the original study, the patients were randomised into two separate groups, an intensive exercise group, and a regular exercise group. The subsequent training for the intensive exercise group included a functional exercise programme with emphasis on high intensity of endurance, strength, and balance for the whole first year after stroke. The patients in the regular exercise followed regular procedures with no specific exercises but were tested regularly, as described elsewhere [10–12]. However, both groups were equally active in this first year after stroke and both maintained function, as opposed to earlier studies with no activities after stroke [13]. When the groups were rearranged in functional capacity groups, the exercise patterns at 36 months after stroke showed no significant difference between the groups ($P = 0.6$). In the MAS group <35 a total of 73% were active with regular exercise with a coach (53%) or self-training (20%) versus MAS group >35, where 82% were active, 50% with self-training, and 32% with a coach during the first year after stroke.

2.4. Statistical Analysis. The results were analysed in an SPSS programme version 19. Descriptive statistics were used to summarise demographic, stroke, and baseline characteristics. All analyses were performed on an intention-to-treat basis. Baseline demographics and exercise levels between groups were performed with a one-way analysis of variance. The functional groups MAS <35> were analysed in a general linear model for repeated measurements, with mixed between-within subjects analysis of variance (ANOVA) was performed, using change from baseline, 3, 12, and 36 months after stroke in MAS, BBS, BI, TUG, and 6MWT. Furthermore, the same functional groups MAS <35> were analysed in relation to the original exercise groups' stratification, presented in an earlier study [10–12], in a general linear model multivariate analysis. The significance level was set at $P < 0.05$.

Table 1: Demographics at baseline when admitted to the hospital in the two groups MAS ≤35 and MAS >35.

	Group MAS <35 ($n = 37$)	Group MAS >35 ($n = 38$)	P-value
Age (years)	76.8 (12.9)	70.2 (12.9)	0.03
Males/females	20/17	23/15	0.6
Days in hospital	27.5 (9.7)	10.6 (6.7)	0.001
Medication per day	6.1 (3.1)	5.9 (3.2)	0.8
Systolic blood pressure	167.4 (39)	153.8 (28.6)	0.09
Diastolic	93.9 (19.5)	85.4 (19.3)	0.06
Cerebral infarction/ haemorrhage	28/9	37/1	0.08
Right/left	17/20	21/17	0.4
Married/single	23/14	20/18	0.7
Community support/none	8/29	2/36	0.2

Table 2: Change scores in mean and SD between baseline and 36 months after stroke in two groups in Motor Assessment Scale (MAS), Berg Balance Scale (BBS), Barthel Index (BI), Timed Up and Go (TUG), 6-Minute Walk Test (6MWT) and P-values.

	MAS <35 ($n = 27$)	MAS >35 ($n = 37$)	P-value
MAS	13.2 (13.8)	2 (3.3)	0.001
BBS	18.9 (20.7)	4.3 (11.3)	0.001
BI	35 (38)	4.7 (9.8)	0.001
TUG	+8.6 (35.0)	−3.5 (6.0)	0.06
6MWT	152.2 (170.4)	194.5 (167.9)	0.3

3. Results

Demographic and descriptive data indicate that group MAS <35 was significantly older, initially spent more days in the hospital/rehabilitation unit, and had higher blood pressure than MAS >35 during the period of the study (Table 1). There were significant differences between the groups, as expected, in total MAS ($P < 0.001$), BBS ($P < 0.001$), TUG ($P < 0.001$), 6MWT ($P < 0.001$), and BI ($P < 0.001$) (Table 2) at all test occasions. The Group MAS <35 had lower scores in all tests than group MAS >35 overall, motor function (MAS) were on admission 15.3 versus 44.4 and at 36 months 29 versus 47. The scores for balance (BBS) at the same time periods were 10 versus 50 and 29 versus 53, respectively. Activities of daily living (BI) presented total scores 31 versus 94 and 66 versus 99 in the same groups. Mobility (TUG) presented slower performance in MAS <35 than MAS >35 at baseline 17 s versus 11 s, and at 36 months after stroke 26 s versus 7.6 s, and walking capacity was shorter, 46 m versus 370 m, 198 m versus 565 m in the groups, respectively.

However, both groups improved their motor function as measured with MAS (Figure 2), ADL as measured with

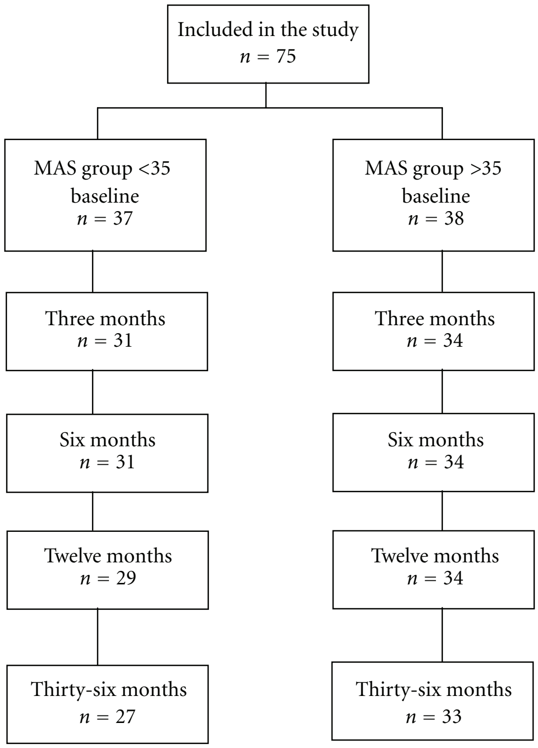

Figure 1: Flow chart of numbers of patients included in the study at each test occasion during a 26-month period.

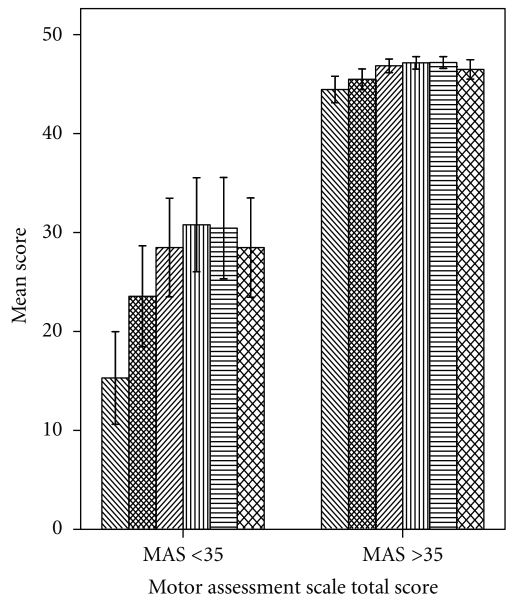

Figure 2: Motor function measured with Motor Assessment Scale total score in the groups MAS <35 (1) and MAS >35 (2) at baseline, discharge, 3, 6, 12, and 36 months, presented in mean with indicated standard errors.

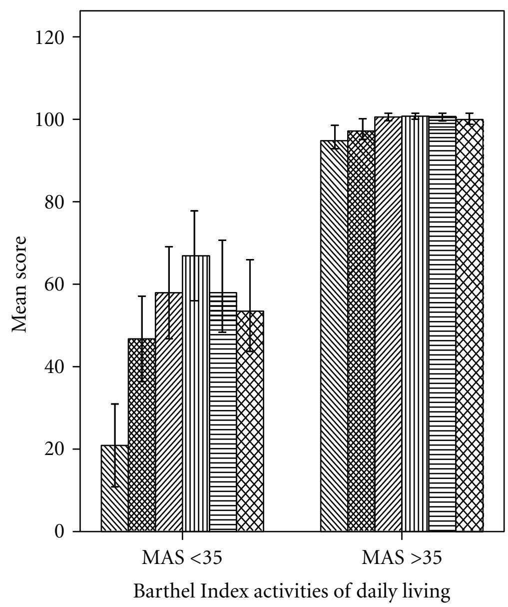

Figure 3: Barthel Index activities of daily living in the groups MAS <35 (1) and MAS >35 (2) at baseline, discharge, 3, 6, 12, and 36 months after stroke, presented in mean total scores with indicated standard error.

BI (Figure 3), balance as measured with BBS (Figure 4), and mobility as measured with TUG (Figure 5) up till six months were it stabilized and stayed till twelve months for to slightly decline. This tendency was in general more prominent in the Group MAS <35. However, change scores showing the rate of improvement from baseline to 36 months after stroke indicated a greater potential for rehabilitation in the MAS <35 in relation to group MAS >35 (Table 2).

Walking capacity (6MWT) improved up till twelve months in both groups, for to show slight deterioration in both groups at the 36-month followup (Figure 6).

The functional groups MAS <35 and MAS >35 analyzed within the original different exercise regimens showed the same significant differences between functional status in total MAS scores ($P < 0.001$), BI ($P < 001$), BBS ($P < 0.001$), TUG ($P < 0.001$), and 6MWT ($P < 0.001$). However, an interesting indication was observed between the organized exercise—and voluntary exercise group regarding improvements from six months to twelve and thirty-six months after stroke in both MAS <35 and MAS >35 (Figure 7). Voluntary exercise group showed a slightly better maintenance of function in both MAS <35 and MAS >35 at twelve and thirty-six months after stroke as exemplified by the 6 Minute Walk Test (Figure 7), the difference was not significant ($P = 0.6$, $P = 0.3$) but the tendency was the same in MAS, BI, BBS, and TUG tests.

4. Discussion

4.1. Improvement Pattern. Both groups improved their capacities and function up till six months after stroke where the gains plateaued for motor function, balance, mobility, and ADL. The findings are inline with, and confirm results from other studies that motor function, and activities show a pattern of improvement up till three to six months after stroke [34, 35]. The peak of performance and optimal function seems to be established at six months after stroke [10–12, 34, 35]. The regained optimal performance is dependent on maintenance of capacities and activities in order to be

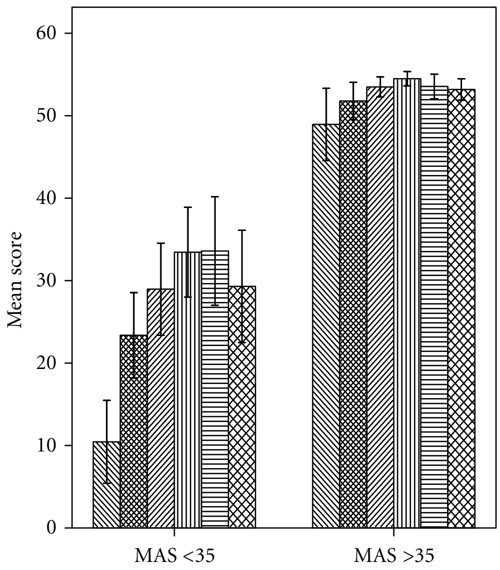

Figure 4: Balance measured with Berg Balance Scale in the groups MAS <35 (1) and MAS >35 (2) at baseline, discharge, 3, 6, 12, and 36 months after stroke, presented in mean scores with indicated standard error.

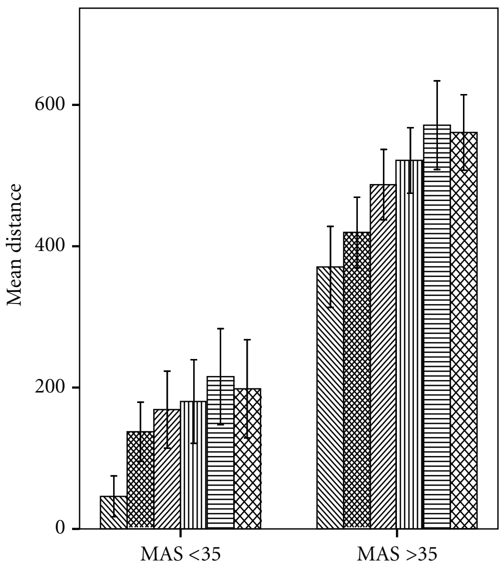

Figure 6: Walking capacity measured with 6 Minute Walk Test in the groups MAS <35 (1) and MAS >35 (2) at baseline, discharge, 3, 6, 12, and 36 months after stroke, presented in mean distance walked with indicated standard error.

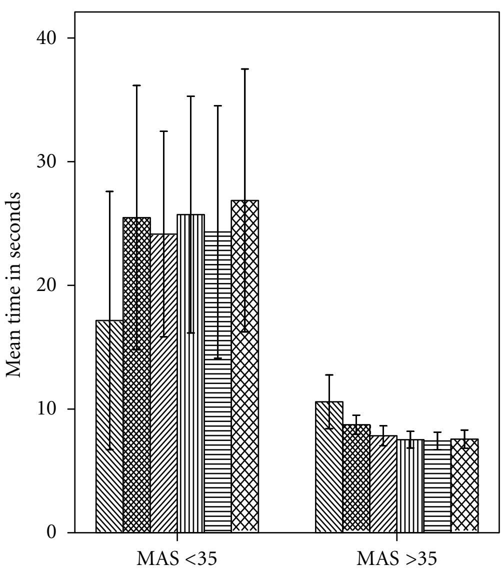

Figure 5: Timed Up and Go in the groups MAS <35 (1) and MAS >35 (2) at baseline, discharge, 3, 6, 12, and 36 months after stroke, presented in mean time with indicated standard error.

sustained, and if training is not provided the performance is likely to deteriorate [13]. This is inline with physical function in the general population and the recommendations for physical activity [20].

Motor function, balance, and ADL, on the other hand in the MAS group <35, had a steeper improvement pattern than in the MAS group >35 which indicated that persons with moderate and severe stroke are highly susceptible for exercise and training although they did not reach the same functional levels as persons with minor stroke. This is inline with other studies, which have shown that persons with a low capacity increase their capacity to a higher degree than a person who has higher capacity, if exercising [20].

Mobility, as measured with Timed Up and Go, stabilized at six months, then deteriorated in the MAS group <35, but remained stable in MAS group >35 (Table 2). The task getting up from a chair, move around, and return to the chair is repeated several times during the day, and, thus, in theory, it would be maintained, as hypothesized in the "use it or lose it" theory [36]. The MAS group >35 presents scores that are well within the limits for a comparable group of healthy elderlies already at three months after stroke and maintain this function on a group level up till 36 months. The MAS <35, however, had difficulty with the task at baseline and instead of improving as time passed, they deteriorated and, on a group level, they were much slower than their healthy counterparts and the MAS group >35 at 36 months. Explanatory factors might be that the task is complex and requires power, coordination, and perception to a higher degree than walking on an even surface. The bodily capacities strength and power are known to deteriorate with age [16–18]. In combination with the paresis in a patient with stroke, which might lead to poor coordination and in combination with reduced perception, it will have severe influence on performance, more so in a complex than in a simple task. One might also speculate if the combination of reduced capacity in several body functions after a stroke in combination with age-related changes might reinforce each other.

Walking capacity in terms of distance but also in speed showed a slightly different pattern than the other parameters in this study. The improvement continued up till twelve months, for to stabilize and then slightly show deterioration

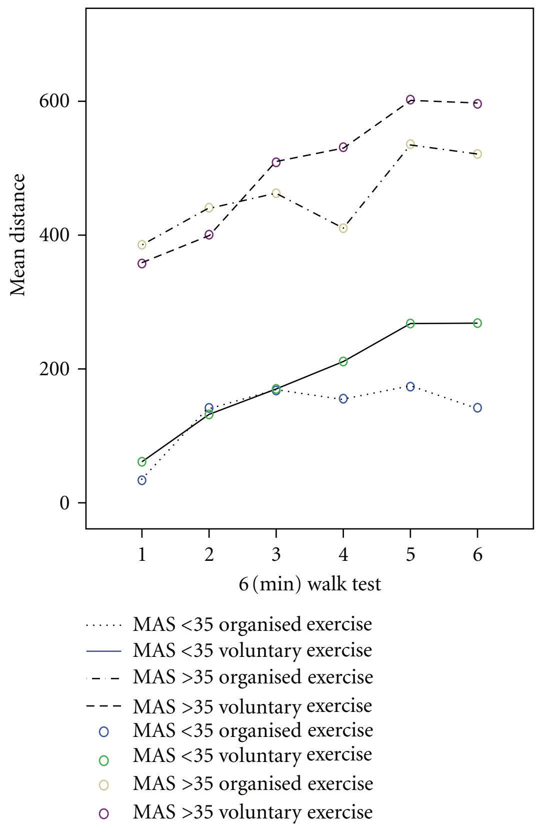

Figure 7: Walked distance measured with 6 Minute Walk Test at baseline, discharge, 3, 6, 12, and 36 months after stroke. Groups are divided in functional level: MAS <35> and subgroups: organized versus voluntary exercise.

at the assessment at 36 months after stroke (Table 2). Exercises were maintained up till one year in the original trial, and exercise patterns were similar in frequency and intensity in both groups, and as a consequence the functional capacity was also maintained up to one year [10–12]. But, as the trial ended, so did the regular tests and support from the research team to the participants and as a result functional capacity slightly declined inline with use-it-or-loose-it theories [36]. However, the decline in walking capacity at three years was more severe for in the MAS group <35, because of the lower capacity at baseline and at the 12-month assessment. This indicates the importance of some sort of extra exercises in this group. The energy cost when walking with less motor function will be higher, and asymmetry may impose more strain on structures, joints, and weight bearing soft-tissue which might cause pain or discomfort, all of which will indirect influence capacity and endurance [37].

The fact that our better performers had a slower progress on the scales MAS, BBS, and BI is to some extent explained by the fact that they reach maximum scores/ceiling effect, faster than the poorer performers. Scores in MAS, BBS, and BI are ordinal scales compared with the outcome measures 6MWT and TUG which, on the other hand, are quantitative and therefore there is no floor or ceiling effect [28]. So, for high performers, the ordinal scale becomes less sensitive to change than for the low performers.

4.2. Difference in Performance between the Functional Groups. The groups were divided according to their function at baseline. This also turned out to be predicative for their longitudinal development, where MAS group <35 showed a lower performance all through the three years as compared to MAS group >35. This supported the first part of the hypothesis that the functional gain during the period would be lower in persons with more severe stroke. However, the MAS group <35 improved their scores approximately with 46% in MAS, 73% in 6MWT, 65% in BBS, and 53 in % BI compared to the MAS group >35 with 4% in MAS, 25% in 6MWT, 8% in BBS, and 5% in BI from baseline to three months after stroke (Table 2). The improvements in the MAS <35 group were major, and, in regard to priority discussions, for whom rehabilitation is worthwhile, this would indicate that persons with <35 on a MAS total score should be at focus for rehabilitation. This was contrary to our second part of the initial hypothesis that progress in rehabilitation would go slower. Instead it went faster in the group with poorer function. The same tendency has also been observed in regard to poor physical function and physical activity among healthy persons where the persons with less physical capacity gain function in a more rapid tempo than their counterparts with a better physical capacity at baseline [20].

On the other hand, the MAS group <35 had in total scores function and capacity below norm levels in walking, mobility, with fall risk, and dependence in ADL, whereas the MAS group >35 was comparable to healthy counterparts [31]. Also in regard to TUG, the MAS group <35 showed a decline with 33% compared to MAS group >35, which improved with 46% from baseline to 36 months after stroke (Table 2). This indicated that TUG, as a complex functional activity, might be predictive of function to a higher degree than the other outcome measures used in this study.

4.3. Improvement Pattern and Performance in the Functional Groups in Relation to Exercise. The improvement patterns showed the same directions when analyzed in the original exercise groups in regard to function. The MAS >35 group was stronger in performance, but the MAS <35 group showed a steeper improvement curve. However, the exercise regimens, organized versus voluntary, had an interesting influence on performance 6, 12, and 36 months after stroke in favor of voluntary exercises both for MAS <35 and MAS >35 (Figure 7). This tendency underlines the importance of empowerment and self-efficacy for the individual in a long-term context of rehabilitation but also for motor learning [38]. Both persons in MAS <35 and MAS >35 had a better progress when they could decide themselves when and how the physical exercise should take place (Figure 7). All persons participating in the studies were tested regularly. This had a positive influence in itself on motivation and goal achievement [10–12]. However, the organized exercise group seemed to be more reliant on their "contact PT" to maintain exercises, whereas the voluntary group themselves organized their training in accordance with the possibilities provided in the community. So, the voluntary group was equally active and frequency of exercise was the same as in the organized group [10–12]. The results indicate enhanced empowerment and health-related quality of life in favor of the voluntary group for both MAS <35> [11]. Explanatory factors may be that in order to make the rehabilitation process "your own," to learn, retain and transfer motor abilities, internal augmentation is of main importance, rather than external augmentation from a therapist. It seems vital that the individual is personally involved and motivated in the planning and execution of training. The tendencies in this study show that this is equally applicable to persons with high and low functional level after stroke (Figure 7).

The exercises were in the organized group standardized so that the participants should maintain a high intensity, 2-3 times a week. In combination with daily activities, this was hypothesized to facilitate and maintain motor learning and improve physical fitness [39]. The voluntary group, on the other hand, decided their time and exercise schedules, from their individual status, based on their test results. The intensity levels of the programmes were reported by the participants themselves, and there was no control other than the test occasions. Endurance capacity was indirectly measured with 6MWT, and the tendency of the group supports the impression of increased capacity in the voluntary group compared to the organized (Figure 7).

However, as the registration of exercise levels showed, both groups exercised on a higher intensity than what is defined as physical activity [20, 39]. Despite this, the results indicate a poorer physical fitness level (6MWT) in the MAS <35 group than MAS >35 group at both 12 and 36 months, 216 m versus 577 m, and 198 m versus 565 m, respectively. In comparison, a healthy older person of the same mean age and nationality perform is mean 617 m (SD 78.6) [40].

These results capture the difficulty with rehabilitation where persons that can achieve independence are at priority. The persons gaining most function from rehabilitation does not seem to be the ones that will gain independence but the ones that will still need some assistance. So, in many ways, the functional gains the MAS group <35 achieved are very important in view of secondary problems after stroke like immobility, pain, and incontinence. The improvements will not only have an impact on health-related quality of life, family life, and the individual's coping strategies, but one would assume also for health care costs.

The impressive improvements in the MAS <35 indicates a need for alternative rehabilitation for this disabled, but not independent group also in a longitudinal perspective. The MAS group <35 had not the bodily capacities which enables them to maintain function on a self-supportive level as the "use-it-or-lose-it" theory implies.

The MAS group >35, on the other hand, seems to be able to return to their ordinary lives and achieve a high functioning level with little or no problems in motor function, balance, mobility, and activities of daily living (Table 2). The abilities seem to be maintained through "daily use" and through self-training. This is inline with the "use-it-or loose-it" theories, but it also underlines the fact that in order for this theory to be valid, the individual needs the bodily capacities to be *able* to "use it."

There are some weaknesses in this study. The sample size was relatively small at three-year followup (Figure 1) due to several factors. In many ways, this illuminates a typical development over time in a population of stroke; mortality is high in this group; in addition dementia is not un-common as part of the secondary problems a person with stroke might encounter and some dropped out because it was too strenuous to get to the clinic for a test. A larger sample size would have made up for the dropouts and the results less vulnerable, but this was not an option in this study from the beginning. Another weakness is related to exercises which were not standardized from one year till three years after stroke, neither were they standardized in time, but there are to our knowledge no studies indicating any particular recommendations in this respect. Rather the contrary, persons with stroke are expected to continue their lives and social roles and cease being patients after their initial rehabilitation.

5. Conclusion

The functional capacities in acute stroke patients have a major impact on motor function, balance, mobility, and activity of daily living in a longitudinal perspective, where persons with stroke with MAS <35 at baseline show a lower performance in all our tests from baseline to 36 months after stroke. MAS group >35 improved functional abilities over the three years and could return to their homes and social roles. However, stroke patients with MAS <35 at baseline showed a better improvement relatively, thus indicating the importance of maintenance of exercise and training after stroke for all persons with stroke. The importance of possibilities to maintain function after stroke regardless of functional level was also confirmed.

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