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Tremelo, June 2014 N.D.W.

RESEARCH CONTEXT

In 2007, the MS network Limburg (http://www.uhasselt.be/msnetwerklimburg) was established to facilitate the collaboration between REVAL (PHL), BIOMED (UHasselt) and the Rehabilitation and MS Center Overpelt. Prof. Dr. Bart Van Wijmeersch (promotor of this master thesis) is appointed as researcher and neurologist specialized in Multiple Sclerosis (MS) at the three partners of the network. The research presented in this master thesis is embedded within this framework and fits within the PhD project of Dra. Ilse Lamers (PhD student at Hasselt University and daily supervisor of the master thesis). The PhD project aims to provide more insights into upper limb assessment in MS and the relationship between disability on the different levels of the International Classification of Functioning (ICF).

MS is a chronic auto-immune disease of the central nervous system, with the first signs appearing in the young adulthood (1). About one in 1000 people living in the Western Countries have the diagnosis of MS, with a higher prevalence rate for woman (1). MS is a neurodegenerative and progressive disease of the central nervous system causing different symptoms such as problems with mobility, upper limb dysfunction, bladder and bowel dysfunction, sexual dysfunction, depression, cognitive impairment and fatigue (1;2).

About 60% of the PwMS perceive upper limb dysfunction in the first year after the onset of the disease (2). PwMS report to use their upper limbs less frequently and with a lower quality of movement compared to healthy persons (3). Furthermore, in comparison with healthy persons, PwMS have decreased handgrip strength and manual dexterity (3). Adequate upper limb function is important to perform tasks in daily life, like preparing a meal, buttoning clothes and the use of a mobile phone. (4). An early identification of upper limb dysfunction in PwMS is important in order to start as early as possible with rehabilitation (4). An early intervention is important to counter restrictions in daily living and to maintain a good quality of life (4).

Several clinical outcome measures are used to assess upper limb function in PwMS (5). However, current upper limb assessment tools have their limitations (5). For example, most frequently used outcome measures assess muscle strength, spasticity and coordination, mostly in a unilateral way (5). However, impairments such as reduced selective movements and movement speed accompanied by increased variability are rarely investigated (5). Repetitive finger-thumb opposition movements or also called Finger Tapping (FT), may be a promising assessment tool to evaluate these impairments. Through the complex integration of motor function, bilateral activity and concentration, FT may be able to detect early upper limb dysfunction in PwMS and it may be sensitive to detect changes is upper limb function. Therefore, the aim of this master thesis is to investigate the psychometric properties and clinical utility of FT in PwMS.

In order to evaluate FT objectively, sensor-engineered gloves and an associated software programme were developed in collaboration with Prof. Dr. ir. Ronald Thoelen (Industrial Sciences, UHasselt) and Prof. Dr. ir. Michaël Daenen (Industrial Sciences, UHasselt). The literature review of the first part of my master thesis provided us crucial information to develop the gloves and to determine the test parameters of FT.

The research protocol of this master thesis was developed based on the findings of the literature review and in collaboration with Prof. Dr. Bart Van Wijmeersch, Prof. Dr. Peter Feys and Dra. Ilse Lamers. With the support of Dra. Ilse Lamers, I have requested the approval of the Ethics Committee. I have recruited the participants of the study. Data collection was performed by Dra. Ilse Lamers and myself. The data-analysis, statistical analysis and writing the master thesis was mainly independent work, with daily support of Dra. Ilse Lamers.

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Finger Tapping as an outcome measure to assess upper limb dysfunction in Multiple Sclerosis: a pilot study on feasibility and psychometric properties

Opgesteld volgens de richtlijnen van ‘Multiple Sclerosis Journal’: http://msj.sagepub.com

Abstract

Background: There is a lack of upper limb outcome measures in Persons with Multiple Sclerosis (PwMS) which assess impairments of selective finger movements and variability in performance. Repetitive finger-thumb oppositions or also called Finger Tapping (FT), may be a promising clinical outcome measure to assess upper limb dysfunction in PwMS.

Objective: This pilot study aimed to investigate the feasibility, performance, reliability and concurrent validity of FT protocols in PwMS and healthy controls, using a newly-developed sensor-engineered glove.

Methods: Ten PwMS and ten gender, hand dominance and age-matched healthy controls were included. Clinical outcome measures on 'body functions and structures' level and 'activity' level of the International Classification of Functioning (ICF) were conducted. During two test sessions on different days, two FT tasks were performed twice: index-thumb opposition and finger-thumb opposition movements. All FT tasks were performed both unimanual and bimanual, at both maximum speed and at a paced speed of 2Hz. The following parameters were investigated: amount of taps (n), inter-tap interval (s), touch duration (s) and inter-hand interval (s).

Results: Clinical outcome measures revealed impaired arm-hand function in PwMS**.** In general, PwMS performed the FT tasks slower, with less taps, a longer inter-tap interval and touch duration compared to healthy controls. Good intra-session reliability was found for the latter FT parameters (ICC>0.75), however the results showed moderate to low between-session reliability in both groups (ICC<0.74). The FT parameters correlated well with pinch grip strength, sensory function and the NHPT in PwMS. Inter-hand interval showed poor discriminative capacities, reliability and correlations with clinical outcome measures.

Conclusions: FT is an easy and well tolerated assessment tool which parameters can discriminate between PwMS and healthy controls. Moderate reliability of FT was found in this study. FT correlated well with upper limb outcome measures in PwMS. Further research in lager study groups is recommended to obtain more powerful analysis.

Keywords

Multiple Sclerosis, upper extremity, outcome assessment, psychometrics, finger tapping

Introduction

Multiple Sclerosis (MS) is a chronic auto-immune and neurodegenerative disease of the central nervous system and results in diffuse demyelisation and axonal atrophy (1). Persons with MS (PwMS) present with a wide variety of signs and symptoms such as muscle weakness, spasticity, tremor, sensory dysfunction, bladder and bowel dysfunction, sexual dysfunction, cognitive impairment, fatigue and social dysfunction (6). According to Holper et al., about three quarters of PwMS report to have upper limb dysfunction (6). Recently, Lamers et al. showed that PwMS had significant less handgrip strength, impaired manual dexterity and moved their arms less frequently with a lower self-reported quality of movement compared to healthy controls (3). Due to this impaired upper limb function, PwMS may experience problems while performing several tasks of daily living which require adequate functioning of the arms and hands such as, pouring water or to tie shoelaces (4). Therefore, upper limb dysfunction in PwMS may result in restrictions in independency, quality of life and participation within the community (4).

An early detection of upper limb dysfunction in PwMS is important to counter these restrictions in daily life and to provide appropriate rehabilitation strategies (4). To date, different upper limb outcome measures, such as the Nine Hole Peg Test (NHPT), the Action Research Arm Test (ARAT) and Box and Block Test (BBT) are frequently used to identify upper limb dysfunction in PwMS (3-5;7).

Despite the good psychometric properties and clinical utility of these tests (3-5;7;8), they have some limitations. Ceiling effects are reported for the ARAT in PwMS with limited upper limb dysfunction (3;5;7). Therefore, it may be possible that PwMS with early upper limb dysfunction will be overlooked. The NHPT and BBT only provide information about the speed of performance, but offer no information on the reason of impaired performance neither on the quality of movement. Furthermore, the NHPT and BBT require grip function of the hand (5). It may be possible that PwMS are not able to perform these outcome measures when they have difficulties to perform a pinch grip, especially for the NHPT (5). Furthermore, these outcome measures may be not able to identify subtle dysfunctions in the early stage of the disease (5). New, objective and sensitive clinical measures are needed to better identify upper limb dysfunction and disease progression in PwMS. Recently, Bonzano et al. described ‘Finger Tapping’ (FT), a repetitive task of finger-thumb opposition movements, as a quantitative and objective measurement to identify upper limb motor control in PwMS (9). The results of this study indicated that FT can be used to discriminate between healthy controls and PwMS with a low Expanded Disability Status Scale (EDSS) score (9). This finding provides evidence that FT may be an appropriate assessment tool to identify early upper limb dysfunctions in PwMS. A possible advantage of FT could be the combination of motor function, bilateral activity and the required concentration which might results in an early detection of upper limb dysfunction in PwMS. However, limited evidence is available about the psychometric properties of FT in PwMS and about the relationship with other upper limb outcome measures. Therefore, the aim of this study is to investigate the feasibility of conducting FT while wearing a newly developed sensor-engineered glove.

This study also aims to investigate the performance of FT in PwMS and to investigate the reliability and validity of the FT parameters.

Method

Participants

PwMS were recruited from the patient database of the Hasselt University and the Rehabilitation and MS Centre Overpelt, Belgium. Persons older than 18 years with the diagnosis of MS according to the McDonald criteria (10) were included. Persons with orthopaedic or rheumatic problems in the upper limbs were excluded from the study. Gender, hand dominance and age-matched healthy controls were recruited via family and acquaintances.

The study was approved by the Ethics Committee of the University of Hasselt, KULeuven and the Rehabilitation and MS Centre Overpelt. Each participant signed the informed consent before participation in the study.

Descriptive outcome measures

In order to describe the sample, the disease duration, the type of MS and the EDSS score were determined by the neurologist. In addition, the hand dominance was determined by the Edinburgh Handedness Inventory (11).

The general fatigue was determined by using the Visual Analogue Scale (VAS) (12). The Symbol Digit Modalities Test (SDMT) was used to assess the cognition of the participants (13).

Clinical outcome measures

Clinical outcome measures on the 'body functions and structure' level and 'activity' level of the International Classification of Functioning (ICF) model were performed with both upper limbs in a random order.

Clinical tests on 'body functions and structure' level of ICF. The maximum isometric pinch grip strength (kg) was measured by using a pinch dynamometer of the Elink (Biometrics) (14). Participants performed three trials with each hand. The mean score of the three trials was used in the data analysis. The tactile sensitivity of the fingertips was assessed by the use of the Semmes-Weinstein Monofilaments (six point ordinal scale, normal score is 0) (15). Five flexible nylon fibers with different diameters (2.83, 3.61, 4.31, 4.56 and 6.65) were randomly applied on each fingertip. A score "0" was given to those who were able to feel three times the smallest monofilament (2.83). Respectively, a score of "1", "2", "3" and "4" were given when a participant was able to detect the monofilament of diameter 3.61, 4.31, 4.56 and 6.65 three times. When a participant was not able to feel the largest monofilament (6.65) a score of "5" was given.

Clinical tests on 'activity' level of ICF. The NHPT was used to determine fine manual dexterity (16;17). The participants were asked to place nine pegs in nine holes and remove these pegs afterwards as fast as possible (number of pegs/second). Gross manual dexterity was assessed by the use of the BBT (7;18). During one minute, the participants had to remove as much blocks as possible from one box to the other. A coin rotation task (CRT) was performed to assess in-hand manipulation (19;20). Twenty 180° rotations with a Nickel were performed as fast as possible between the thumb, index and middle finger. The time needed to complete the test was registered. Furthermore, the Manual Ability Measure (MAM) was used to determine the perceived difficulty to perform 36 functional tasks (maximum score is 100) (21).

Finger tapping

Finger tapping system. A sensor-engineered glove consisting of conductive textile at the finger tips which serves as contact sensors was developed by the department of Industrial Sciences (UHasselt) (Figure 1). The contact sensor at the fingertip of the thumb is connected with the ground voltage. The other four fingers are connected with the digital inputs of the Arduino (open-source electronics prototyping platform). When a finger makes contact with the thumb, the input of the finger is pulled to the ground voltage. The Arduino will detect the transition from the ground voltage to zero and will send the collected data to the connected computer.

A software programme developed in Labview was used to determine the following parameters after data collection: amount of taps, inter-tap interval, touch duration and inter-hand interval. The time between two successive contacts of a finger with the thumb of the same hand is defined as the inter-tap interval. Touch duration is measured by the time of contact between the thumb and the other finger. The inter-hand interval means the time difference between both hands when the thumb makes contact with the same finger and when the touch is released.

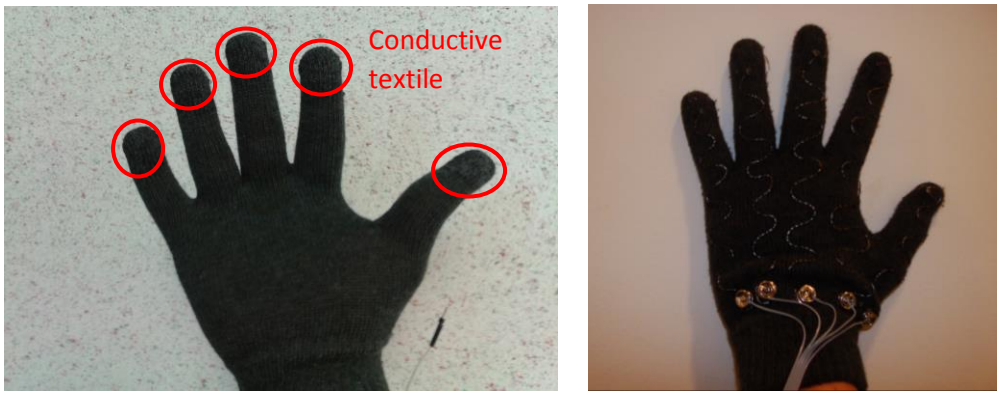

Figure 1. Sensor-engineered glove.

Finger Tapping tasks and test procedure. The participants were asked to perform two different FT tasks while wearing the sensor-engineered gloves. One task consisted of a repetitive movement between the index and the thumb (Figure 2a), the other task consisted of a repetitive movement between the thumb and the other four fingers of the same hand (sequential order) (Figure 2b). The order of the sequential FT task started at the index, the next fingers were the middle finger and the ring finger, and the last finger in the sequence was the little finger. After the thumb made contact with the little finger, the sequence started over again at the index. Each task was performed twice: on a maximum speed and on a paced speed of 2 Hz. The left hand and the right hand were both tested separately as well as simultaneously. Each condition was performed three times during one minute, with one minute rest between the test trials. The first trial of every condition was a practice trial and is not included in the data analysis. An overview of the FT test procedure is presented in table 1. The order of the different FT conditions was randomly assigned. In order to avoid compensatory strategies for the impaired motor ability by visual feedback, the participants were asked to close their eyes during test performance. The participants were seated in a comfortable chair without arm rests.

Figure 2a. Index-thumb.

Figure 2b. Sequential.

Table 1. Test procedure of the Finger Tapping.

Index – thumb			**Sequential**		
Speed	Maximum	2 Hz	Speed	Maximum	2Hz
Left hand	2x1 minute, 1 minute rest	2x1 minute, 1 minute rest	**Left hand**	2x1 minute, 1 minute rest	2x1 minute, 1 minute rest
Right hand	2x1 minute, 1 minute rest	2x1 minute, 1 minute rest	**Right hand**	2x1 minute, 1 minute rest	2x1 minute, 1 minute rest
Bimanual	2x1 minute, 1 minute rest	2x1 minute, 1 minute rest	**Bimanual**	2x1 minute, 1 minute rest	2x1 minute, 1 minute rest

Study procedure

All measures were conducted in three test sessions, each lasting about one hour. During the first test session, the descriptive and clinical outcome measures were conducted. During the other two test sessions, the FT procedure was performed. After the last FT procedure, the participants filled in a questionnaire to evaluate the feasibility of the 'Finger Tapping System' (appendix 1). The current state of fatigue (VAS) was conducted every test session.

Statistical analysis

Statistical analysis were executed by IBM SPSS statistics 22, with a significance level set on $p<0.05$. Due to the small sample size, non-parametric tests were used. Differences between PwMS and healthy controls on the clinical outcome measures and on the FT parameters were calculated by the use of the Mann-Whitney U test. A Wilcoxon signed-rank test was used to investigate the differences between the dominant and non-dominant hand on the clinical tests. Intra-session variations of a subject during a FT task was investigated by calculating Intra-class Correlation Coefficients (ICC) between the data of trial two and three during the session on one test day. To investigate the between-session reliability, ICC between the mean of trial two and three of a FT task on test day one was compared with the mean of trial two and three on test day two. The ICC were defined as excellent with a value higher than 0.90, good between 0.75 and 0.90, moderate between 0.50 and 0.74 and poor when a value was below 0.50. In addition, the Standard Error of Measurement (SEM) was calculated by the square root of the mean square error term from the analysis of variance (ANOVA). The relationship between the clinical tests and FT was investigated using Spearman coefficients, providing information of the validity of FT.

Results

Participants

Descriptive characteristics of the ten included PwMS are presented in table 2. In addition, ten gender-, age- and hand dominance-matched healthy controls (mean age=55.50 with SD=9.53 years; six females; eight right handed) participated in the study.

Table 2. Descriptive characteristics of PwMS (n=10).

Gender	
Male (n)	4
Female (n)	6
Mean age (years)	55.50 (SD ± 9.53)
Handdominance	
Right handed (n)	8
Ambidextrous (n)	2
Median EDSS score [range]	4.0 [2.5 – 6.0]
Type MS	
Relapsing Remitting MS (n)	6
Secondary Progressive MS (n)	4
Mean disease duration (years)	21.30 (SD ± 9.13)
Median VAS-fatigue [range]	4.95 [1.93-5.93]
Mean SDMT	30.30 (SD ± 8.9)

n: number; SD; standard deviation; SDMT: Symbol Digit Modalities Test.

Clinical measures

Table 3 presents an overview of the results on the clinical outcome measures. PwMS had significant less pinch grip strength in their fingers ($p<0.01$) and showed significant more impaired sensory function of the fingertips ($p<0.05$).

Furthermore, PwMS scored significant worse on the manual dexterity measurements (NHPT $p<0.05$, BBT $p\leq0.01$, CRT $p<0.001$) and they perceived more difficulties in performing ADL tasks (MAM $p<0.001$).

In both groups, no significant differences were found between both hand

Table 3. Clinical outcome measures performed with the left and the right hand for PwMS (n=10) and healthy controls (n=10). Differences between both hands were calculated by the use of a Wilcoxon signed-rank test. Mann-Whitney U tests were used to calculate the differences between the study groups. Level of significance was set on 0.05.

	MS group					**Control group**					**MS group vs. control group**	
	Left hand		Right hand			Left hand		Right hand			Left hand	Right hand
	median	(25^{th}-75^{th} IQR)	median	(25^{th}-75^{th} IQR)	p-value	median	(25^{th}-75^{th} IQR)	median	(25^{th}-75^{th} IQR)	p-value	p-value	p-value
Clinical tests on function level												
Pinch grip strength (kg)	4.40	(3.60-5.30)	4.20	(3.70-5.42)	ns	8.00	(7.40-9.40)	8.35	(7.60-9.20)	ns	p<0.001	p<0.001
Semmes-Weinstein monofilaments (0-5)												
Thumb	3.00	(3.00-4.00)	3.00	(3.00-4.25)	ns	2.50	(2.00-3.00)	2.50	(2.00-3.00)	ns	p<0.05	p<0.05
Index	3.00	(3.00-3.25)	3.00	(2.50-4.50)	ns	2.00	(2.00-3.00)	2.50	(2.00-3.00)	ns	p<0.05	ns
Middle finger	3.00	(3.00-3.25)	3.00	(3.00-3.00)	ns	2.00	(2.00-3.00)	2.00	(2.00-3.00)	ns	p<0.05	p<0.05
Ring finger	3.00	(2.25-4.00)	3.00	(3.00-3.00)	ns	2.00	(2.00-3.00)	2.00	(2.00-3.00)	ns	ns	p<0.01
Little finger	3.00	(2.00-3.50)	3.00	(2.00-3.00)	ns	2.00	(2.00-3.00)	2.00	(2.00-3.00)	ns	ns	ns
Clinical tests on activity level												
Nine Hole Peg Test (pegs/s)	0.32	(0.26-0.45)	0.36	(0.32-0.45)	ns	0.45	(0.41-0.48)	0.47	(0.44-0.53)	ns	p<0.05	p<0.05
Box and Block Test (n)	48.50	(38.25-50.50)	47.50	(44.75-50.25)	ns	56.50	(51.00-60.50)	57.50	(51.00-61.00)	ns	p<0.01	p<0.001
Coin rotation task (s)	27.53	(26.29-45.13)	23.68	(22.39-32.11)	ns	18.54	(17.54-19.83)	17.33	(15.33-19.32)	ns	p<0.001	p<0.001
Manual Ability Measure	56.5	(52.88-62.63)				89.25	(74.63-100.00)				p<0.001	

IQR: Interquartile range; ns: not significant.

Feasibility of the Finger Tapping system

In general, the glove fits well according to all the subjects of both groups (table 4). Both groups found the task moderately difficult to perform and exhausting (table 4). No side effects (e.g. itch, rash) of the glove were reported (table 4).

Table 4. Feasibility of the 'Finger Tapping System' in PwMS and healthy controls.

	MS group		Control group	
	median	(25^{th} – 75^{th} IQR)	median	(25^{th} -75^{th} IQR)
The glove fits around the fingers	4.70	(4.75-.500)	5.00	(5.00-5.00)
The glove fits around the hand	5.00	(4.75-5.00)	5.00	(5.00-5.00)
The glove limits the movement in the fingers	1.00	(1.00-1.00)	1.00	(1.00-2.50)
The glove limits the movement in the hand	1.00	(1.00-1.00)	1.00	(1.00-2.25)
The glove is too loose	1.00	(1.00-1.00)	1.00	(1.00-1.00)
Perceived difficulty of the task	3.00	(2.75-4.25)	3.00	(2.00-3.50)
Task induced fatigue	4.00	(3.00-4.00)	3.00	(1.75-5.00)
Side effects	0.00	(0.00-0.00)	0.00	(0.00-0.00)

IQR: Interquartile range.

Performance of the Finger Tapping procedure and differences between study groups

Amount of taps. In general, the healthy controls performed significant more taps compared to the PwMS during the FT tasks at maximum speed (table 5). At paced speed, no significant differences for the amount of taps were found between both study groups (table 5). Apart from the bimanual sequential FT task performed by PwMS, participants performed more taps during the maximum condition compared to the paced condition (table 5). For example when performing the index-thumb FT task with the right hand, PwMS tapped 146 times during the maximum condition and 119 times during the paced condition (table 5).

Inter-tap interval. The median inter-tap intervals during the maximum FT tasks in healthy controls were shorter compared to those found in PwMS (table 5). When comparing the FT tasks at maximum speed, in both groups the inter-tap interval takes longer during the sequential condition compared to the index-thumb condition (table 5). At paced speed, the median inter-tap interval fluctuates around 0.50 seconds in both groups (table 5).

Touch duration. In general, touch duration was higher in PwMS in comparison with healthy controls (table 5). In both groups, the contact time between two fingers was longer when performing the sequential FT task compared to the index-thumb FT task, at both the maximum and paced speed. (table 5).

Inter-hand interval. No significant differences between the study groups were found for the inter-hand interval (table 5).

In conclusion, during the FT tasks, PwMS perform less taps, at a slower inter-tap interval and with a longer touch duration compared to healthy controls.

Table 5. Performance of the Finger Tapping procedure in PwMS (n=10) and healthy controls (n=10). The median of the two test trials on the first test day was calculated for the different FT parameters of the 12 FT tasks. Differences between PwMS and healthy controls were calculated by the use of the Mann-Whithey U Test. Level of significance was set on 0.05.

	MS group				Control group				MS group vs. control group	
	Left		Right		Left		Right		Left	Right
	median	(25^{th}-75^{th} IQR)	median	(25^{th}-75^{th} IQR)	median	(25^{th}-75^{th} IQR)	median	(25^{th}-75^{th} IQR)	p-value	p-value
IT_MAX										
Amount of taps (n)	144	(115-178)	146	(112-174)	185	(172-198)	152	(108-197)	p<0.05	ns
Inter-tap interval (s)	0.42	(0.34-0.52)	0.41	(0.34-0.53)	0.32	(0.30-0.34)	0.40	(0.30-0.55)	p<0.05	ns
Touch duration (s)	0.16	(0.14-0.17)	0.15	(0.11-0.20)	0.09	(0.07-0.12)	0.07	(0.05-0.12)	p<0.01	p<0.01
IT_MAX_BM										
Amount of taps (n)	139	(123-153)	143	(125-178)	201	(153-226)	178	(148-219)	p<0.01	p<0.05
Inter-tap interval (s)	0.43	(0.39-0.49)	0.42	(0.33-0.48)	0.30	(0.26-0.39)	0.36	(0.28-0.42)	p<0.01	ns
Touch duration (s)	0.17	(0.12-0.21)	0.14	(0.11-0.18)	0.09	(0.06-0.12)	0.08	(0.05-0.10)	ns	p<0.001
Inter-hand interval (s)	-0.36	(-1.09-1.00)[a]			0.35	(-0.16-2.04)[a]			ns[a]	
IT_2HZ										
Amount of taps (n)	119	(119-120)	119	(118-119)	118	(115-119)	117	(107-118)	ns	ns
Inter-tap interval (s)	0.50	(0.50-0.50)	0.50	(0.49-0.50)	0.50	(0.49-0.51)	0.51	(0.50-0.56)	ns	ns
Touch duration (s)	0.20	(0.18-0.21)	0.18	(0.15-0.21)	0.16	(0.11-0.18)	0.13	(0.11-0.15)	p<0.05	p<0.05
IT_2HZ_BM										
Amount of taps (n)	119	(118-119)	119	(119-120)	119	(118-121)	118	(90-119)	ns	ns
Inter-tap interval (s)	0.50	(0.50-0.51)	0.50	(0.50-0.50)	0.49	(0.48-0.50)	0.50	(0.50-0.58)	ns	ns
Touch duration (s)	0.16	(0.15-0.23)	0.18	(0.15-0.21)	0.14	(0.09-0.19)	0.12	(0.08-0.18)	ns	p<0.05
Inter-hand interval (s)	-0.21	(-3.15-0.51)[a]			0.20	(-0.82-0.22)[a]			ns[a]	
SEQ_MAX										
Amount of taps (n)	102	(98-126)	109	(96-127)	145	(119-157)	136	(115-152)	p<0.01	ns
Inter-tap interval (s)	0.58	(0.47-0.60)	0.55	(0.47-0.62)	0.40	(0.38-0.48)	0.44	(0.39-0.52)	ns	ns
Touch duration (s)	0.25	(0.21-0.29)	0.21	(0.18-0.30)	0.19	(0.17-0.21)	0.16	(0.10-0.19)	ns	p<0.05
SEQ_MAX_BM										
Amount of taps (n)	90	(80-110)	90	(84-100)	128	(112-144)	108	(68-132)	ns	ns
Inter-tap interval (s)	0.66	(0.53-0.72)	0.64	(0.59-0.69)	0.46	(0.41-0.52)	0.51	(0.45-0.74)	p<0.05	ns
Touch duration (s)	0.29	(0.18-0.34)	0.26	(0.22-0.34)	0.17	(0.12-0.23)	0.15	(0.09-0.23)	ns	p<0.01
Inter-hand interval (s)	1.63	(-1.10-2.92)[a]			1.26	(-0.29-3.93)[a]			ns[a]	
SEQ_2HZ										
Amount of taps (n)	115	(107-119)	119	(110-122)	118	(118-119)	111	(96-117)	ns	ns
Inter-tap interval (s)	0.51	(0.49-0.55)	0.50	(0.48-0.54)	0.50	(0.49-0.50)	0.54	(0.50-0.61)	ns	p<0.05
Touch duration (s)	0.24	(0.23-0.26)	0.21	(0.16-0.25)	0.20	(0.17-0.25)	0.18	(0.14-0.22)	ns	ns
SEQ_2HZ_BM										
Amount of taps (n)	116	(100-118)	116	(104-128)	116	(100-120)	116	(105-116)	ns	ns
Inter-tap interval (s)	0.50	(0.49-0.57)	0.50	(0.46-0.55)	0.50	(0.50-0.58)	0.50	(0.50-0.55)	ns	ns
Touch duration (s)	0.24	(0.01-0.27)	0.22	(0.19-0.26)	0.22	(0.18-0.28)	0.19	(0.14-0.23)	ns	ns
Inter-hand interval (s)	-0.48	(-2.17-1.66)[a]			0.23	(0.02-1.60)[a]			ns[a]	

IT_MAX: unimanual index-thumb FT task on maximum velocity; IT_MAX_BM: bimanual index-thumb FT task on maximum velocity; IT_2HZ: unimanual index-thumb FT task on a paced velocity of 2Hz; IT_2HZ_BM: bimanual index-thumb FT task on a paced velocity of 2Hz; SEQ_MAX: unimanual sequential FT task on maximum velocity; SEQ_MAX_BM: bimanual sequential FT task on maximum velocity; SEQ_2HZ: unimanual sequential FT task on a paced velocity of 2 Hz; SEQ_2HZ_BM: bimanual sequential FT task on a paced velocity of 2Hz; n: number; s: seconds; IQR: Interquartile Range; ns: not significant; [a]: inter-hand interval has a bimanual outcome.

Intra-session variations

The results of the intra-session variations in healthy controls and PwMS are presented in table 6a and 6b, respectively. Apart from the paced sequential FT tasks, good to excellent ICC's were found in healthy controls for the parameter 'amount of taps' (table 6a). Low ICC's were found for the inter-tap interval of the unimanual index-thumb FT tasks at maximum speed in healthy controls (table 6a). The other FT tasks showed good to excellent ICC's on the inter-tap interval, however also a large variability was seen in these FT tasks (table 6a). In contrast with the unimanual FT tasks, low ICC's were found for the bimanual FT tasks in healthy controls for the parameter 'touch duration' (table 6a).

High ICC's were found for the parameters 'amount of taps' and 'inter-tap interval' for the FT tasks performed at maximum speed by PwMS (table 6b). In contrast, low ICC's were found for these FT parameters in the bimanual and left handed FT tasks performed at a paced speed of 2 Hz (table 6b). The maximum FT tasks (performed unimanual and bimanual) and the unimanual paced FT tasks performed with the right hand revealed good to excellent ICC's in PwMS on the parameters 'amount of taps', 'inter-tap interval' and 'touch duration' (table 6b).

Finally, moderate to low ICC's were found in both groups for the inter-hand interval (table 6a,b).

Overall, the intra-session variations for a subject are the largest for the inter-hand interval and the least for the amount of taps, the inter-tap interval and the touch duration.

Between-session reliability

High ICC's were found for the parameters 'amount of taps', 'inter-tap interval' and 'touch duration' during the bimanual sequential FT task at maximum speed in healthy controls (table 7a). In general, large variabilities in the amount of taps between the two test days are seen in both groups (table 7a, b). The bimanual FT tasks at maximum speed revealed excellent to good ICC's for the parameter 'inter-tap interval' in healthy controls (table 7a). In contrast to healthy controls, high ICC's were found in PwMS for the touch duration between two fingers (table 7b). Inter-hand interval showed a low between-session reliability in both groups (table 7a, b).

In general, FT has a moderate between-session reliability when it is performed by healthy controls and PwMS.

Table 6a. Intra-subject variation for the parameters of the different FT-tasks in healthy controls (n=10). ICC was calculated from the amount of taps, the mean inter-tap interval, touch duration and inter-hand interval measured during the two test trials on test day 1. Significance level was set at 0.05.

	Amount of taps						*Inter-tap interval*						*Touch duration*						*Inter-hand interval*		
	Left			Right			Left			Right			Left			Right					
	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound
IT_MAX	0.45	-0.16	0.83	0.82†	0.15	0.96	0.29	-0.32	0.75	0.38	-0.17	0.79	0.49	-0.14	0.84	0.98†	0.91	0.94			
IT_MAX_BM	0.99†	0.96	0.99	0.97†	0.87	0.99	0.99†	0.94	0.99	0.94†	0.77	0.99	0.06	-0.52	0.65	-0.05	-0.67	0.60	0.63*	-0.14	0.91
IT_2HZ	0.87†	0.49	0.97	0.76†	0.26	0.94	0.92†	0.58	0.98	0.76†	0.28	0.94	0.91†	0.65	0.98	0.72†	0.20	0.93			
IT_2HZ_BM	0.95†	0.73	0.99	0.91†	0.65	0.91	0.97†	0.86	0.99	0.93†	0.73	0.99	-0.29	-0.84	0.49	-0.14	-0.72	0.58	0.59	-0.27	0.93
SEQ_MAX	0.99†	0.98	0.99	0.96†	0.84	0.99	0.98†	0.92	0.99	0.90†	0.66	0.97	0.83†	0.44	0.96	0.91†	0.69	0.98			
SEQ_MAX_BM	0.78†	0.28	0.95	0.93†	0.67	0.99	0.95†	0.80	0.99	0.54	-0.10	0.87	0.29	-0.38	0.78	0.16	-0.52	0.72	-0.06	-0.43	0.58
SEQ_2HZ	0.41	-0.32	0.84	0.67†	0.18	0.91	0.80†	0.26	0.96	0.61*	0.07	0.88	0.94†	0.06	0.99	0.83†	0.45	0.96			
SEQ_2HZ_BM	0.58*	-0.12	0.89	0.51	-0.25	0.87	0.42	-0.32	0.83	0.80†	0.32	0.95	0.08	-0.43	0.64	0.93†	0.68	0.99	-0.03	-0.72	0.69

IT_MAX: unimanual index-thumb FT task on maximum velocity; IT_MAX_BM: bimanual index-thumb FT task on maximum velocity; IT_2HZ: unimanual index-thumb FT task on a paced velocity of 2Hz; IT_2HZ_BM: bimanual index-thumb FT task on a paced velocity of 2Hz; SEQ_MAX: unimanual sequential FT task on maximum velocity; SEQ_MAX_BM: bimanual sequential FT task on maximum velocity; SEQ_2HZ: unimanual sequential FT task on a paced velocity of 2 Hz; SEQ_2HZ_BM: bimanual sequential FT task on a paced velocity of 2Hz; ICC: Intra-class Correlation Coefficient; *: $p<0.05$; †:$p<0.01$.

Table 6b. Intra-subject variations for the parameters of the different FT-tasks in PwMS (n=10). ICC was calculated from the mean amount of taps, the mean inter-tap interval, the mean touch duration and the mean inter-hand interval measured during the two test trials on test day 1. Significance level was set at 0.05.

	Amount of taps						*Inter-tap interval*						*Touch duration*						*Inter-hand interval*		
	Left			Right			Left			Right			Left			Right					
	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound	ICC	Lower Bound	Upper Bound
IT_MAX	0.77†	0.35	0.94	0.88†	0.50	0.97	0.64*	0.11	0.89	0.93†	0.65	0.99	0.80†	0.32	0.95	0.93†	0.73	0.98			
IT_MAX_BM	0.94†	0.77	0.98	0.91†	0.59	0.98	0.92†	0.72	0.98	0.95†	0.79	0.99	0.92†	0.71	0.98	0.97†	0.88	0.99	0.73*	0.15	0.93
IT_2HZ	-0.36	-0.75	0.63	0.79†	0.35	0.95	-0.09	-0.76	0.59	0.77†	0.30	0.94	0.71*	0.15	0.93	0.86†	0.46	0.97			
IT_2HZ_BM	-0.02	-0.61	0.64	0.55	-0.13	0.89	-0.01	-0.63	0.65	0.43	-0.25	0.85	0.53*	-0.09	0.88	0.93†	0.53	0.99	0.47	-0.22	0.90
SEQ_MAX	0.86†	0.48	0.97	0.88†	0.58	0.97	0.88†	0.54	0.97	0.87†	0.55	0.97	0.96†	0.84	0.99	0.94†	0.77	0.99			
SEQ_MAX_BM	0.94†	0.76	0.98	0.78†	0.32	0.94	0.89†	0.48	0.97	0.78†	0.32	0.94	0.90†	0.63	0.98	0.78†	0.33	0.94	0.59*	-0.11	0.93
SEQ_2HZ	0.38	-0.29	0.80	0.90†	0.63	0.98	0.37	-0.31	0.80	0.91†	0.67	0.98	0.66*	0.11	0.90	0.77†	0.32	0.94			
SEQ_2HZ_BM	0.53	-0.26	0.89	0.26	-0.44	0.79	0.78†	0.20	0.95	0.22	-0.49	0.77	0.66*	0.06	0.92	-0.43	0.91	0.37	-0.18	-0.67	0.57

IT_MAX: unimanual index-thumb FT task on maximum velocity; IT_MAX_BM: bimanual index-thumb FT task on maximum velocity; IT_2HZ: unimanual index-thumb FT task on a paced velocity of 2Hz; IT_2HZ_BM: bimanual index-thumb FT task on a paced velocity of 2Hz; SEQ_MAX: unimanual sequential FT task on maximum velocity; SEQ_MAX_BM: bimanual sequential FT task on maximum velocity; SEQ_2HZ: unimanual sequential FT task on a paced velocity of 2 Hz; SEQ_2HZ_BM: bimanual sequential FT task on a paced velocity of 2Hz; ICC: Intra-class Correlation Coefficient; *: $p<0.05$; †:$p<0.01$.

Table 7a. Test-retest reliability (ICC, SEM) for the parameters of the different FT-tasks in healthy controls (n=10). The parameters mean of the two test trials of every test day were compared. P-value of significance was set on 0.05.

	Amount of taps				*Inter-tap interval*				*Touch duration*				*Inter-hand interval*	
	Left		Right		Left		Right		Left		Right			
	ICC	SEM	ICC	SEM	ICC	SEM	ICC	SEM	ICC	SEM	ICC	SEM	ICC	SEM
IT_MAX	0.392	52.56	0.80*	39.85	0.29	0.23	0.562	0.35	0.42	0.25	-0.24	0.19		
IT_MAX_BM	0.57	46.69	0.44	51.35	0.85†	0.05	0.93†	0.08	0.45	0.18	-0.56	0.29	-0.67	1.32
IT_2HZ	0.12	6.79	0.78	5.32	0.10	0.03	0.81	0.02	0.50	0.03	0.78*	0.00		
IT_2HZ_BM	-2.00	0.74	0.07	1.54	-0.07	0.00	-0.01	0.14	-1.29	0.08	-0.32	0.14	2.43	0.32
SEQ_MAX	0.22	45.81	0.25	34.60	0.26	0.06	-0.04	0.42	-0.24	0.03	-0.01	0.45		
SEQ_MAX_BM	0.88†	2.44	0.90†	2.70	0.89†	0.25	0.93†	0.21	0.88*	0.07	0.65	0.20	0.38	1.47
SEQ_2HZ	0.07	12.07	0.83*	6.72	0.02	0.08	0.73*	0.05	0.90†	0.00	0.73	0.02		
SEQ_2HZ_BM	0.97†	0.67	0.23	3.54	0.98†	0.04	0.15	0.31	-0.45	0.22	0.29	0.20	0.22	1.07

IT_MAX: unimanual index-thumb FT task on maximum velocity; IT_MAX_BM: bimanual index-thumb FT task on maximum velocity; IT_2HZ: unimanual index-thumb FT task on a paced velocity of 2Hz; IT_2HZ_BM: bimanual index-thumb FT task on a paced velocity of 2Hz; SEQ_MAX: unimanual sequential FT task on maximum velocity; SEQ_MAX_BM: bimanual sequential FT task on maximum velocity; SEQ_2HZ: unimanual sequential FT task on a paced velocity of 2 Hz; SEQ_2HZ_BM: bimanual sequential FT task on a paced velocity of 2Hz; ICC: Intra-class Correlation Coefficient; SEM: Standard Error of Measurement; *:$p<0.05$; †: $p<0.01$.

Table 7b. Test-retest reliability (ICC, SEM) for the parameters of the different FT-tasks in PwMS (n=10). The parameters mean of the two test trials of every test day were compared. P-value of significance was set on 0.05.

	Amount of taps				*Inter-tap interval*				*Touch duration*				*Inter-hand interval*	
	Left		Right		Left		Right		Left		Right			
	ICC	SEM	ICC	SEM	ICC	SEM	ICC	SEM	ICC	SEM	ICC	SEM	ICC	SEM
IT_MAX	0.66	35.26	0.58*	21.98	-0.52	0.13	0.50	0.10	0.27	0.05	0.51*	0.03		
IT_MAX_BM	-0.20	33.44	0.35	29.01	-0.25	0.09	0.17	0.09	0.65	0.03	0.53	0.04	0.32	1.84
IT_2HZ	0.20	5.24	0.27	13.31	0.17	0.03	-0.16	0.06	-2.35	0.04	0.87†	0.02		
IT_2HZ_BM	-0.20	21.34	-0.05	20.05	-0.01	0.08	0.07	0.06	0.83*	0.03	0.88†	0.00	0.11	0.87
SEQ_MAX	0.40	29.79	0.89†	7.67	0.62	0.13	0.88†	0.03	0.52	0.06	0.79*	0.05		
SEQ_MAX_BM	-0.24	9.48	-0.98	5.21	-0.27	0.68	-0.96	0.49	-1.43	0.12	-0.10	0.57	-0.28	2.60
SEQ_2HZ	0.78*	4.76	0.54	11.62	0.77*	0.02	-0.05	0.08	0.51	0.04	0.83†	0.02		
SEQ_2HZ_BM	0.03	5.61	-1.60	7.71	-0.27	0.55	0.35	0.37	0.01	0.15	-0.78	0.16	-1.46	1.54

IT_MAX: unimanual index-thumb FT task on maximum velocity; IT_MAX_BM: bimanual index-thumb FT task on maximum velocity; IT_2HZ: unimanual index-thumb FT task on a paced velocity of 2Hz; IT_2HZ_BM: bimanual index-thumb FT task on a paced velocity of 2Hz; SEQ_MAX: unimanual sequential FT task on maximum velocity; SEQ_MAX_BM: bimanual sequential FT task on maximum velocity; SEQ_2HZ: unimanual sequential FT task on a paced velocity of 2 Hz; SEQ_2HZ_BM: bimanual sequential FT task on a paced velocity of 2Hz; ICC: Intra-class Correlation Coefficient; SEM: Standard Error of Measurement; *:$p<0.05$; †: $p<0.01$.

Correlations between FT parameters and clinical tests in PwMS

Correlations between outcome measures on the 'body functions and structures' and 'activity' level and the parameters of the different FT tasks are presented in PwMS (table 8a-9b). The bimanual index-thumb FT task at maximum speed (table 8b) and the unimanual sequential FT task at maximum speed (performed with the right hand) (table 9a) were significantly correlated with the pinch grip strength. The pinch grip strength showed significant correlations with the amount of taps and significant correlations with the inter-tap interval (table 8b, 9a). The tactile sensitivity of the thumb was moderately to highly correlated with the inter-tap interval and touch duration of sequential FT tasks, both at maximum and paced speed (table 9a, b). The NHPT (pegs/s) was significantly correlated with the parameters 'amount of taps', 'inter-tap interval' and 'touch duration' during the index-thumb FT task at paced speed (table 8a,b). A moderate correlation between the NHPT (pegs/s) and the inter-tap interval during a left handed sequential FT task at maximal speed was found (table 9a). Furthermore, significant correlations were found between the NHPT (pegs/s) and the touch duration during the sequential FT tasks performed at maximum speed (table 9a,b). Unimanual FT conditions performed at maximum speed showed significant correlations between the BBT and the touch duration of FT (table 8a, 9a). High correlations were found between the MAM and the FT parameters 'amount of taps', 'inter-tap interval' and 'touch duration' of the bimanual FT tasks (table 8b, 9b). Low correlations were found between the inter-hand interval and the clinical outcome measures (table 8b,9b).

This means that the performance of a FT task correlates well with pinch grip strength, preserved sensitivity and the NHPT, and less with the BBT. Especially bimanual FT tasks correlates well with the MAM.

Table 8a. Spearman Correlation Coefficients of the unimanual index-thumb FT-tasks in PwMS (n=10). Significance level was set on 0.05.

	IT_MAX						**IT_2HZ**					
	Amount of taps		*Inter-tap interval*		*Touch duration*		*Amount of taps*		*Inter-tap interval*		*Touch duration*	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Clinical Tests on function level												
Pinch grip strength	0.03	0.32	-0.14	-0.03	0.20	-0.17	0.17	-0.56	-0.03	0.59	-0.15	-0.28
Semmes-Weinstein Monofilaments												
Thumb	0.01	0.24	-0.06	-0.12	0.54	0.02	0.26	-0.44	-0.17	0.43	0.09	0.00
Index	-0.09	0.58	0.02	-0.08	0.47	-0.13	-0.09	-0.35	0.18	0.35	0.18	0.17
Middle finger	-0.23	0.16	0.23	-0.16	0.20	0.08	-0.14	-0.28	0.22	0.27	0.28	0.18
Ring finger	0.04	-0.31	-0.24	0.23	0.45	0.23	-0.14	-0.28	0.22	0.28	0.28	0.18
Little finger	-0.34	0.35	0.16	0.00	0.70*	0.09	-0.09	-0.28	0.18	0.28	0.18	0.18
Clinical tests on activity level												
Nine Hole Peg Test (pegs/s)	-0.18	-0.46	0.23	0.10	-0.12	-0.12	0.74*	-0.22	-0.74*	0.21	-0.13	-0.38
Box and Block Test	-0.21	-0.21	0.24	0.13	0.01	-0.21	0.72*	-0.22	-0.63	0.25	-0.18	-0.75*
Coin Rotation Task (s)	0.31	-0.23	-0.24	0.52	-0.14	0.73*	0.17	-0.40	-0.22	0.35	-0.20	-0.58
Manual Ability Measure	0.03	-0.22	0.03	0.43	0.06	0.67*	0.31	0.43	-0.41	-0.42	-0.17	-0.11

IT_MAX: unimanual index-thumb FT task on maximum velocity; IT_2HZ: unimanual index-thumb FT task on a paced velocity of 2Hz; *: $p<0.05$; †:$p<0.01$.

Table 8b. Spearman Correlation Coefficients of the bimanual index-thumb FT-tasks in PwMS (n=10). Significance level was set on 0.05.

	IT_MAX_BM								**IT_2HZ_BM**							
	Amount of taps		*Inter-tap interval*		*Touch duration*		*Inter-hand interval*		*Amount of taps*		*Inter-tap interval*		*Touch duration*		*Inter-hand interval*	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Clinical tests on function level																
Pinch grip strength	-0.53*	-0.55*	0.53*	0.45	0.58†	0.43	0.10	-0.02	-0.12	-0.07	0.26	0.59	0.05	-0.35	-0.09	-0.32
Semmes-Weinstein Monofilaments																
Thumb	-0.07	0.24	0.07	-0.05	-0.20	-0.27	-0.16	-0.22	0.00	-0.11	0.11	0.55	-0.22	-0.44	-0.10	0.21
Index	0.00	-0.15	0.00	0.29	-0.20	-0.14	-0.30	-0.18	-0.28	0.28	0.39	0.00	-0.39	0.218	0.21	0.29
Middle finger	-0.02	0.14	0.02	-0.08	-0.38	-0.25	-0.24	-0.38	-0.34	0.29	0.40	0.17	-0.48	-0.17	0.14	0.21
Ring finger	-0.30	0.37	0.30	-0.29	-0.09	-0.58†	-0.31	-0.08	-0.34	0.29	0.40	0.17	-0.48	-0.17	0.14	0.21
Little finger	-0.04	-0.27	0.04	0.27	-0.26	0.01	-0.35	-0.12	-0.28	0.29	0.39	0.17	-0.39	-0.17	0.21	0.21
Clinical tests on activity level																
Nine Hole Peg Test (pegs/s)	0.19	0.12	-0.19	-0.24	0.28	0.19	0.50*	0.35	0.39	-0.80*	-0.39	0.42	0.78*	0.33	0.20	0.33
Box and Block Test	-0.08	-0.37	0.08	0.27	0.42	0.34	0.24	0.18	0.26	-0.10	-0.14	-0.02	0.59	0.20	-0.31	-0.17
Coin Rotation Task (s)	0.28	0.25	-0.28	-0.11	-0.42	-0.17	-0.48	-0.47	-0.14	-0.17	0.07	0.00	0.29	0.02	-0.37	-0.71
Manual Ability Measure [a]	-0.48*	-0.50*	0.48*	0.38	0.65†	0.45	0.11[a]		0.85†	0.04	-0.88†	-0.56	0.54	0.71*	0.40[a]	

IT_MAX_BM: bimanual index-thumb FT task on maximum velocity; IT_2HZ_BM: bimanual index-thumb FT task on a paced velocity of 2Hz; [a]: Manual ability measure makes no difference between the left and the right hand; *: p<0.05; †:p<0.01.

Table 9a. Spearman Correlation Coefficients of the unimanual sequential FT-tasks in PwMS (n=10). Significance level was set on 0.05.

	SEQ_MAX						**SEQ_2HZ**					
	Amount of taps		*Inter-tap interval*		*Touch duration*		*Amount of taps*		*Inter-tap interval*		*Touch duration*	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Clinical Tests on function level												
Pinch grip strength	0.17	-0.63*	0.49	0.63*	0.62	-0.51	0.00	-0.13	-0.19	0.13	-0.38	0.02
Semmes-Weinstein Monofilaments												
Thumb	0.09	-0.40	0.62	0.40	0.56	0.55	0.00	-0.24	-0.06	0.24	-0.17	0.24
Index	0.14	-0.49	0.55	0.49	0.68*	0.55	-0.39	-0.17	0.38	0.17	-0.13	0.38
Middle finger	-0.26	-0.22	0.21	0.22	0.21	0.49	-0.39	-0.36	0.38	0.36	-0.13	0.28
Ring finger	-0.04	-0.49	0.64	0.49	0.37	0.32	-0.39	-0.34	0.38	0.34	-0.13	-0.04
Little finger	0.01	-0.37	0.47	0.37	0.29	0.08	-0.39	-0.36	0.38	0.36	-0.13	0.28
Clinical tests on activity level												
Nine Hole Peg Test (pegs/s)	0.46	0.44	-0.57	-0.44	-0.23	-0.70*	0.14	0.16	-0.19	-0.16	0.00	-0.29
Box and Block Test	0.23	-0.11	-0.12	0.11	0.40	-0.68*	-0.31	0.01	-0.11	-0.01	-0.07	-0.59
Coin Rotation Task (s)	-0.21	0.02	0.69	-0.02	0.81*	0.83†	0.07	-0.31	0.00	0.31	-0.12	-0.25
Manual Ability Measure	-0.09	0.18	0.01	-0.18	0.16	0.45	-0.24	0.11	0.00	-0.11	0.29	-0.06

SEQ_MAX: unimanual sequential FT task on maximum velocity; SEQ_2HZ: unimanual sequential FT task on a paced velocity of 2 Hz; *: $p<0.05$; †:$p<0.01$.

Table 9b. Spearman Correlation Coefficients of the bimanual sequential FT-tasks in PwMS (n=10). Significance level was set on 0.05.

	SEQ_MAX_BM								**SEQ_2HZ_BM**							
	Amount of taps		*Inter-tap interval*		*Touch duration*		*Inter-hand interval*		*Amount of taps*		*Inter-tap interval*		*Touch duration*		*Inter-hand interval*	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Clinical tests on function level																
Pinch grip strength	-0.24	-0.50	0.60	0.50	-0.13	0.29	-0.18	0.04	-0.38	0.13	0.68*	-0.02	-0.34	-0.18	-0.08	-0.34
Semmes-Weinstein Monofilaments																
Thumb	-0.39	-0.70*	0.61	0.70*	0.00	0.22	0.09	0.00	-0.62	0.44	0.87†	-0.26	0.00	0.26	-0.09	-0.26
Index	-0.32	-0.04	0.46	0.09	0.37	0.30	-0.27	-0.52	-0.28	0.44	0.55	-0.26	-0.37	0.17	-0.46	-0.61
Middle finger	-0.40	-0.37	0.52	0.46	0.44	0.32	-0.27	-0.27	-0.34	0.37	0.57	-0.09	-0.23	0.09	-0.40	-0.46
Ring finger	-0.40	-0.37	0.52	0.46	0.44	0.32	-0.27	-0.27	-0.34	0.37	0.57	-0.09	-0.23	0.09	-0.40	-0.46
Little finger	-0.32	-0.37	0.46	0.46	0.37	0.32	-0.27	-0.27	-0.28	0.37	0.55	-0.09	-0.37	0.09	-0.46	-0.46
Clinical tests on activity level																
Nine Hole Peg Test (pegs/s)	0.08	0.38	-0.35	-0.50	-0.77*	-0.55	0.52	0.03	-0.05	-0.19	-0.07	-0.13	0.13	-0.01	0.53	0.23
Box and Block Test	-0.08	-0.22	0.09	0.08	-0.61	-0.56	0.24	0.56	-0.25	-0.61	0.39	0.36	-0.19	-0.63	0.18	0.31
Coin Rotation Task (s)	0.18	0.01	-0.42	-0.03	-0.42	-0.19	0.43	0.37	0.17	-0.55	-0.42	0.59	0.10	-0.42	0.23	0.37
Manual Ability Measure [a]	0.72*	0.55	-0.49	-0.60	-0.54	-0.56	0.15[a]		-0.17	-0.51	-0.08	0.22	0.25	-0.29	0.23	

SEQ_MAX_BM: bimanual sequential FT task on maximum velocity; SEQ_2HZ_BM: bimanual sequential FT task on a paced velocity of 2Hz; [a]: Manual ability measure makes no difference between the left and the right hand; *: $p<0.05$; †:$p<0.01$.

Discussion

The present study investigated differences on the parameters ‘amount of taps’, ‘inter-tap interval’ and ‘touch duration’ between PwMS and healthy controls. Furthermore, these FT parameters showed a better intra-session reliability in both study groups compared to the ‘inter-hand interval’. The between-session reliability of FT revealed to be moderate in both study groups. Finally, the clinical outcome measures of pinch grip strength, sensory function of the fingertips, NHPT and MAM was highly correlated with the FT parameters ‘amount of taps’, ‘inter-tap interval’ and ‘touch duration’. This was the first study in PwMS investigating the reliability of FT and correlates the FT performance with upper limb outcome measures. Up to now, FT is commonly used as a task in fMRI-studies to determine brain activity in PwMS (22). Only a few study describes FT as an outcome measure in PwMS (9).

Feasibility

The sensor-engineered gloves were easy to use in practice and were well tolerated by the participants. All the participants were able to perform the different FT tasks. In general, during the data collection participants perceived the sequential FT tasks as more difficult when compared to the index-thumb FT tasks.

Finger Tapping performance

In accordance to the study of Bonzano et al., PwMS showed a slowed performance on the FT tasks at maximum speed (9). In the latter study, less number of taps, longer inter-tap intervals and longer touch durations were found in PwMS compared to healthy controls.

During the FT tasks at a paced speed (2Hz), the tap frequency of the participants in both groups was around 120. This indicates that PwMS were able to perform the FT tasks at this speed. This is in contrast with the study of Bonzano et al., which indicates that PwMS show difficulties with movements at or faster as 2Hz (23). Furthermore, participants were able to perform even more taps when asking them to perform the index-thumb FT task at maximum speed, but not in the sequential task. This may indicate that PwMS are able to perform simple movements at a speed above 2Hz, but present more difficulties to plan sequential FT movements at a speed of 2Hz. Furthermore, the inter-tap interval in the paced conditions fluctuates around 0.50 seconds which indicates that PwMS are able to accurately follow an external cue at a speed of 2Hz.

PwMS showed a significant longer touch duration compared to healthy controls. This is in line with the findings of Bonzano et al., which found longer touch durations for sequential FT tasks in PwMS in comparison with healthy controls (9). Furthermore, longer touch durations for the sequential FT tasks compared to the index-thumb FT tasks were observed in our study. These findings may indicate, as suggested by Bonzano et al., that an impairment in the sensorimotor integration may influence the performance of FT in PwMS (9). This might be partially confirmed by the correlations between touch

duration and sensory dysfunction of the finger tips, which were found in our study. This may indicate that PwMS need longer contact between the thumb and another finger to evaluate with which finger the thumb makes contact. In addition, a study in healthy controls compared the touch duration of FT with increasing complexity of a FT task (24). Three FT tasks were performed in this study: 1. index-thumb FT task, 2. sequential FT task of the thumb to the index, middle finger, ring finger and little finger, and 3. a sequential FT task of the thumb to the index, ring finger, middle finger and little finger (24). A longer contact time was investigated by increasing the complexity of a FT task (25). In summary, the longer touch durations in the sequential FT tasks may be explained by the increased complexity of the FT task and the impaired sensorimotor integration in PwMS.

Intra- and inter-sessions reliability

The intra-session reliability of PwMS was better, with higher correlations and less variation, in the conditions at maximum speed compared to the conditions at paced speed. Furthermore, the index-thumb FT tasks revealed to have higher intra-session reliability compared to the sequential FT tasks. Touch duration seems to be the most consistent parameter between two test days in PwMS. The study of Bonzano et al., investigated a good repeatability in healthy controls when a FT task was performed twice with one month in between (9). The inter-hand interval shows a low intra-session and between-session reliability in both groups and therefore seems not reliable.

Concurrent validity of the Finger Tapping and clinical tests in PwMS

Considering the small force that is required to perform a FT task, low correlations were expected between the finger grip strength and FT. However, significant correlations were found between the pinch grip strength and the FT parameters. A possible explanation may be that a higher force was applied to the fingertips as a compensatory mechanism for the decreased sensory function of the finger tips in PwMS. As assumed, the NHPT correlated better with the FT parameters compared to the BBT. Comparable to FT, the NHPT requires more precise finger grip than the BBT (5). This in line with the results of Bonzano et al, which found significant correlations between a sequential FT task and the NHPT (9). Since the MAM includes mainly bimanual activities of daily living, it is not surprising that the MAM is highly correlated with the bimanual FT tasks.

Methodological considerations

This pilot study discusses different FT tasks, which offers a first perception about the FT performance, the reliability and the validity of possible FT tasks. Furthermore, this study gives a broad framework of correlations by the wide variety of included clinical upper limb outcome measures. One of the limitations of the sensor-engineered gloves may be that we were not able to measure the amplitude of the aperture between the thumb and another finger. This means that variations in amplitude between the thumb and the other fingers during the FT performance, which may affect the FT parameters, were not taken into

account. For example, when a participant performed the FT task with a small amplitude this may lead to a higher number of taps and a smaller inter-tap interval compared to FT with a larger amplitude. In a study of Johansen-Berg et al., a goniometer was attached along the metacarpophalangeal joints of the index finger of healthy subjects to measure the maximum and minimum finger aperture during an index-thumb FT task (26). To minimalize the effect of amplitude variations on the FT parameters, participants in our study were instructed to open the fingers as wide as possible while performing the FT task.
Considering the small sample of this study, further research with a larger sample is recommended for more powerful analysis. Regarding the discriminative capacities, good intra-session reliability and correlations with upper limb outcome measures, we recommend to use index-thumb FT tasks at maximum speed. Additionally, longitudinal studies which investigate possible changes in the performance of FT in relation with disease progression or interventions are recommended. Like the study of Bonzano et al. found a relationship between the EDSS score and the performance of finger movements, it may be interesting to further correlate the FT parameters with outcome measures that can identify disease progression in PwMS, like latency and amplitude of Transcranial Magnetic Stimulation (TMS) measures and neural networks detected by MRI.
Also, studies which investigates the sensitivity and responsiveness of FT to interventions are necessary. In this regard, Bonzano et al. investigated the effects of upper limb rehabilitation on FT and found a significant change of speed during a bimanual FT task in PwMS (27). Furthermore, significant differences on the speed of FT after the rehabilitation were found between the treatment group and control group (27).

Conclusion

FT is an easy and well tolerated assessment tool which can discriminate between PwMS and healthy controls on the base of the amount of taps, inter-tap interval and touch duration. Good intra-session reliability for the latter FT parameters was found. However, moderate between-session reliability of the FT task was investigated in this study. The amount of taps, inter-tap interval and touch duration correlated well with the upper limb outcome measures on the ‘body functions and structures’ level and ‘activity’ level of the ICF. Based on the results obtained by this pilot study we can highlight that further research needs to be conducted on a larger sample size to obtain more powerful analysis considering reliability and validity.

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Ref Type: Unpublished Work

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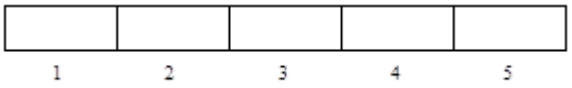
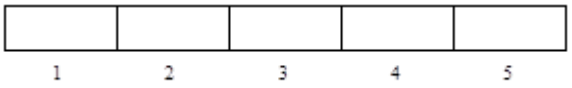
Appendix 1. Feasibility of the 'Finger Tapping System'.

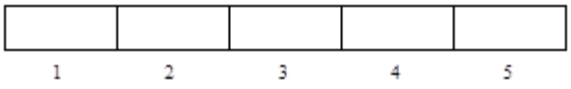
1. The glove fits well around the fingers.

Totally disagree  Totally agree

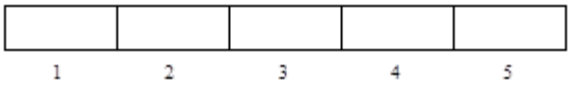
2. The glove fits well around the hand.

Totally disagree  Totally agree

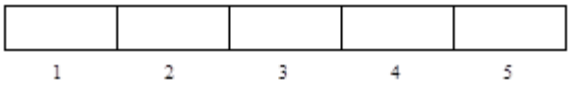
3. The glove limits the movement in the fingers.

Totally disagree  Totally agree

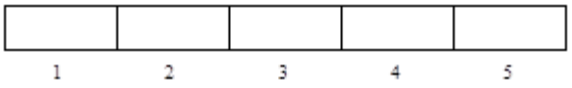
4. The glove limits the movement in the hand.

Totally disagree  Totally agree

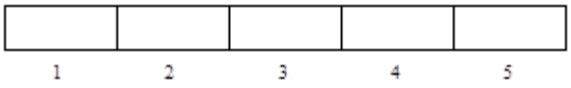
5. The glove is to loose.

Totally disagree  Totally agree

6. The task is easy to perform.

Totally disagree  Totally agree

7. The task is exhausting.

Totally disagree  Totally agree

8. The glove brings side-effects along with it (e.g. itch, rash,…):

○ Yes ○ No

If yes, specify:

9. Comments – suggestions:

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Finger Tapping as an outcome measure to assess upper limb dysfunction in Multiple Sclerosis: a pilot study on feasibility and psychometric properties

Richting: **master in de revalidatiewetenschappen en de kinesitherapie-revalidatiewetenschappen en kinesitherapie bij neurologische aandoeningen**
Jaar: **2014**

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