Upper motor and extra-motor neuron involvement in recent-onset motor neuron disease
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Finger tapping and foot tapping speed measured without devices: reliability and normative values

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Amyotrophic Lateral Sclerosis, submitted

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ABSTRACT

Background
Finger and foot tapping speed (FiTS/FoTS) are used to evaluate motor function in neurological disease. Most studies used equipment not available in daily practice. We obtained reliability data of FiTS and FoTS measured without devices, and generated normative values.

Methods
Two raters counted FiTS and FoTS in 10 healthy individuals using only a stopwatch. The intraclass correlation coefficient (ICC) was used to measure agreement between the two raters, and between each rater and the gold standard (video recordings). A second session in the same individuals provided data on test-retest reliability. We also obtained normative values of FiTS and FoTS in 50 healthy individuals.

Results
Agreement of video recordings with both raters for FiTS in session 1 was lower for rater 1 (ICC 0.86, p=0.001) than for rater 2 (ICC 0.96, p<0.001). In session 2, agreement of video recordings with rater 1 increased (ICC 0.97, p<0.001). Agreement of video recordings with both raters for FoTS was good (ICC 0.98, p<0.001). FiTS was related to age and dexterity, FoTS to gender.

Conclusion
FiTS and FoTS measured without devices proved to be reliable and may thus be used to assess upper motor neuron function in studies and in daily neurological practice.
INTRODUCTION

Finger tapping speed (FiTS) is used to evaluate motor function impairment in diseases of the central nervous system. Decreased FiTS has been described after closed head injury\(^1\), in stroke\(^2-4\) and in Parkinson’s disease\(^7\). Moreover, it has been used as a clinical measure of upper motor neuron function in studies on motor neuron disease\(^8-12\). Foot tapping speed (FoTS) is less widely used but its application is comparable to that of FiTS\(^8, 9, 13, 14\). Interrater reliability of FoTS as a marker for upper motor neuron impairment was shown to be better than that of the Babinski sign\(^15\). Furthermore, FiTS and FoTS are continuous variables, and therefore suitable for monitoring patients over time.

In most studies, FiTS is measured using devices such as a mechanical counter, (mouse) button, keyboard or dynamometer, or alternatively electronic, infrared or magnetic markers or sensors to monitor the speed\(^2-5, 7, 16-18\). However, this equipment is not always available. We performed a MR spectroscopy study on amyotrophic lateral sclerosis and other variants of the motor neuron disease spectrum in which FiTS, measured with no devices other than a stopwatch, proved more accurate to differentiate patients from controls than MRS parameters\(^9\). However, interrater and test-retest reliability of measurement of FiTS and FoTS without the use of registration devices is unknown, and normative values are lacking.

The aim of this study was to obtain interrater and test-retest reliability data of measurement of FiTS and FoTS assessed visually and to determine its reliability with a gold standard. Subsequently, we obtained normative values related to age, gender and dexterity.

METHODS

Reliability study

We enrolled 10 healthy individuals free of neurological disease, all medical students in our academic hospital. They were instructed to sit down at a desk, sit upright with the palms of the hand flat on the table, with the fingers slightly spread. They were asked to tap as quickly as possible with the index finger of the dominant hand for 10 seconds without lifting the palm of the hand. After the finger tapping test the individuals were asked to take off their shoes, sit upright on a chair with the knees flexed approximately
90 degrees and the feet flat on the floor. They were asked to tap the forefoot at the same side of their dominant hand as fast as possible for 10 seconds, without lifting the heel from the floor.

Two raters (MG, JB) visually counted the number of taps, independently from each other. A third person operated the stopwatch counting “three, two, one, start” and after 10 seconds “stop”. A fourth person registered the test with a Sony handheld video camera to be able to provide a “gold standard” on the number of taps per 10 seconds. After a break of 5 minutes the protocol was repeated (session 2), to assess a possible learning effect. The videotapes were played in slow motion (25% of the original speed) using Sony Corporation’s Image Transfer (version 2002.4.22) software and VLC Media Player (version 1.0.3) to assess the actual number of taps. We compared the results of both raters with the “gold standard” (i.e. the number of taps counted when the videotape was played in slow motion), the results of rater 1 (MG) with rater 2 (JB) (intrarater reliability), and the results of session 1 with session 2 (learning effect). The local ethics committee approved the study which was exempt from informed consent.

Normative values per age group
We recruited 10 healthy volunteers for each of the five age groups: 21-30 years, 31-40 years, 41-50 years, 51-60 years and 61-70 years. Volunteers were medical students, hospital employees, partners of patients visiting our outpatient department, and family or friends of the authors. Volunteers with a history of neurological disease, diabetes mellitus, depression, hypothyroidism or alcoholism were excluded. Dexterity, age and gender were registered. The protocol for finger tapping and foot tapping was similar to the protocol as described in the interrater/test-retest reliability section, but now the dominant as well as the non-dominant hand and foot were tested. There was only one rater (JB), who used an audiotape to count down to start and summon “stop” exactly after 10 seconds, as it is not possible to count the taps and to operate the stopwatch at the same time. We also registered FiTS for the thumb and the middle finger. The local ethics committee approved the study which was exempt from informed consent.

Statistical analysis
Reliability study
To determine the agreement on the visually observed number of taps of both raters with the gold standard (videotape) and the agreement on the number of taps observed by rater 1 and by rater 2 we used the intraclass correlation coefficient (ICC). An ICC
larger than 0.80 is considered good. Statistical level of significance was set at p<0.05. Additionally, we constructed Bland–Altman plots of the difference between rater 1 and rater 2 of the observed tapping speed in a single individual against the mean of these two measurements by rater 1 and rater 2 in the same individual. Such a plot demonstrates whether the measurement error is dependent on the magnitude of the observed values. To detect a possible learning effect we analysed the interrater agreement and agreement of both raters with the gold standard also for session 2.

Normative values per age group
We calculated means ± standard deviation per age group. To determine the correlation of FiTS of the third finger and the thumb with FiTS of the index finger we used Pearson’s correlation coefficient. We used a Student’s t-test for paired data to compare means of FiTS of the various tested fingers in the dominant and non-dominant hand, and of FoTS of both sides. We used a Student’s t-test for independent samples to compare means of FiTS (right index finger) and FoTS between male and female individuals. We performed linear regression analysis to evaluate the association between FiTS (right index finger) and FoTS, and age. Statistical level of significance was set at p<0.05, confidence intervals (CI) are given.

Data analysis
We used SPSS 16.0 for Windows for statistical analysis.

RESULTS

Reliability study
Mean age of the 10 volunteers (5 male, 5 female) in this study was 20.9±1.3 years (range 20-24 years), all of them being right-handed as based on self report. Mean FiTS ± standard deviation in session 1 was 56.8 ± 5.2 for rater 1, 56.4 ± 5.3 for rater 2 and 56.6 ±4.4 using video recordings. Mean FoTS ± standard deviation in session 1 was 40.0 ± 6.8 for rater 1, 38.4 ± 7.3 for rater 2 and 39.3 ±7.1 using video recordings. Details on the agreement between visually registered data and the gold standard (video) and interrater agreement between rater 1 (MG) and rater 2 (JB) for session 1 and session 2 are given in Table 1. The Bland-Altman plots (Figure 1A-D) indicate that agreement between observer 1 and observer 2 for FiTS in session 1 diminished as tapping speed was faster (Figure 1A); the difference of the observed FiTS in a single individual between rater
1 and rater 2 tended to increase when the mean of these two ratings within the same individual increased. This tendency was not observed for FITS in session 2 and for FoTS in sessions 1 and 2 (Figure 1B-D).

Table 1. Correlation of visually scored finger and foot tapping speed with the “gold standard”, and interrater reliability

<table>
<thead>
<tr>
<th></th>
<th>ICC FITS</th>
<th>ICC FoTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>session 1</td>
<td>session 2</td>
</tr>
<tr>
<td>rater 1 vs rater 2</td>
<td>0.84</td>
<td>0.95</td>
</tr>
<tr>
<td>rater 1 vs video</td>
<td>0.88</td>
<td>0.97</td>
</tr>
<tr>
<td>rater 2 vs video</td>
<td>0.95</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Abbreviations: ICC, intraclass correlation coefficient; FITS, finger tapping speed; FoTS, foot tapping speed; vs, versus

Video recordings are considered the gold standard. FITS and FoTS of the dominant hand and ipsilateral foot were registered. Statistical level of significance is set at p<0.05. P-values are given in superscript.

Figure 1. Bland–Altman plots of the difference between rater 1 and rater 2 of the observed tapping speed in a single individual (y-axis) against the mean of these two measurements by rater 1 and rater 2 in the same individual (x-axis) for FITS session 1 (A) and session 2 (B), and for FoTS session 1 (C) and session 2 (D). In session 1, the difference of the observed FITS in a single individual between rater 1 and rater 2 tended to increase when the mean of these two measurements within the same individual increased (1A). This tendency was not observed for FITS in session 2 (1B) and for FoTS in session 1 and 2 (1C,1D)

Abbreviations: FITS, finger tapping speed; FoTS, foot tapping speed
Normative values per age group

Description of characteristics per age group is presented in Table 2.

Table 2. Clinical characteristics and mean finger and foot tapping speed per age group

<table>
<thead>
<tr>
<th>Age group (yr)</th>
<th>21-30</th>
<th>31-40</th>
<th>41-50</th>
<th>51-60</th>
<th>61-70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of individuals</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Age (yr) mean (range)</td>
<td>22.7 (21-28)</td>
<td>35.6 (31-40)</td>
<td>45.1 (41-50)</td>
<td>56.2 (52-60)</td>
<td>64.4 (62-69)</td>
</tr>
<tr>
<td>Male/Female</td>
<td>5/5</td>
<td>3/7</td>
<td>4/6</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Dexterity (R/L)</td>
<td>9/1</td>
<td>8/2</td>
<td>10/0</td>
<td>9/1</td>
<td>10/0</td>
</tr>
<tr>
<td>FiTS dig 1 R</td>
<td>54.1 ±6.2</td>
<td>48.5 ±8.2</td>
<td>49.9 ±7.3</td>
<td>46.8 ±6.6</td>
<td>43.1 ±7.6</td>
</tr>
<tr>
<td>FiTS dig 2 R</td>
<td>59.1 ±3.5</td>
<td>53.3 ±7.4</td>
<td>55.1 ±6.8</td>
<td>51.8 ±6.8</td>
<td>49.9 ±6.5</td>
</tr>
<tr>
<td>FiTS dig 3 R</td>
<td>56.2 ±2.8</td>
<td>47.5 ±9.2</td>
<td>53.1 ±6.8</td>
<td>46.5 ±7.1</td>
<td>43.9 ±7.5</td>
</tr>
<tr>
<td>FiTS dig 1 L</td>
<td>48.3 ±5.4</td>
<td>46.0 ±7.8</td>
<td>46.4 ±6.2</td>
<td>41.6 ±7.4</td>
<td>39.9 ±8.3</td>
</tr>
<tr>
<td>FiTS dig 2 L</td>
<td>54.4 ±3.5</td>
<td>49.1 ±7.0</td>
<td>50.5 ±5.1</td>
<td>46.8 ±4.2</td>
<td>44.8 ±5.7</td>
</tr>
<tr>
<td>FiTS dig 3 L</td>
<td>51.8 ±5.7</td>
<td>44.8 ±8.0</td>
<td>48.9 ±5.2</td>
<td>42.0 ±6.0</td>
<td>39.6 ±5.2</td>
</tr>
<tr>
<td>FoTS R</td>
<td>42.3 ±7.8</td>
<td>41.4 ±7.8</td>
<td>37.7 ±5.7</td>
<td>43.5 ±7.0</td>
<td>44.0 ±6.3</td>
</tr>
<tr>
<td>FoTS L</td>
<td>42.1 ±6.2</td>
<td>41.6 ±6.2</td>
<td>36.7 ±6.0</td>
<td>41.6 ±7.3</td>
<td>41.7 ±6.2</td>
</tr>
</tbody>
</table>

Abbreviations: FiTS, finger tapping speed; FoTS, foot tapping speed; R, right side; L, left side; yr, year

Data are presented as means ± standard deviation except indicated otherwise.

Effects of age

FiTS of the right index finger decreased with age (Figure 2A). For every year increase in age, FiTS decreased with 0.2 taps/sec (CI: 0.1-0.3, p= 0.001). FoTS and age were not significantly associated (p=0.70) (Figure 2B).

Figure 2. Scatterplot of tapping speed (y-axis) in relation to age (x-axis) for FiTS (A) and FoTS (B) with a linear regression line fitted.

Abbreviations: FiTS, finger tapping speed; FoTS, foot tapping speed
chapter 5

Effects of dexterity

Four out of 50 individuals were left-handed. This small number did not allow for comparing left handed with right handed individuals. FITS of the index finger was faster than that of the thumb or middle finger (Table 2). In the right hand Pearson’s correlation coefficient between tapping rate of the thumb and the index finger was 0.75 (p<0.001), between the index finger and the middle finger 0.78 (p<0.001). In the left hand, Pearson’s correlation coefficient between tapping of the thumb and the index finger was 0.73 (p<0.001), and between index finger and middle finger 0.75 (p<0.001).

For the 46 individuals who were right-handed, FITS in the dominant hand was significantly faster as compared to the non-dominant hand (P<0.001 for all three tested fingers, CI for the thumb 2.6-5.9, index finger 4.2-6.5, middle finger 2.9-6.1). In only 1 right-handed individual the right index finger tapped slower than the left index finger (a difference of 0.2 taps/sec, results not shown), in all other right-handed individuals the dominant index finger tapped faster than the non-dominant index finger.

Also, in 2 of the 4 left-handed individuals, FITS of the right index finger was faster compared to the left index finger (individual results not shown).

With regard to FoTS there was no influence of dexterity. The FoTS of the right foot was not significantly different from that of the left foot (P=0.1, CI –0.2 – 2.5).

Effects of gender

Differences between male and female individuals are shown in Table 3. FITS did not differ significantly between females and males but FoTS was significantly lower in females than in males.

Table 3. Gender differences in FITS and FoTS

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of individuals</td>
<td>28</td>
<td>22</td>
</tr>
<tr>
<td>age (years)</td>
<td>44.8 ±16.3</td>
<td>44.8 ±14.6</td>
</tr>
<tr>
<td>FITS dig 2 R</td>
<td>55.5 ±5.7</td>
<td>52.6 ±7.2</td>
</tr>
<tr>
<td>FITS dig 2 L</td>
<td>50.1 ±5.3</td>
<td>48.4 ±6.6</td>
</tr>
<tr>
<td>FoTS R</td>
<td>45.2 ±7.4</td>
<td>39.1 ±5.5 [p=0.001 (CI 2.5 – 9.8)]</td>
</tr>
<tr>
<td>FoTS L</td>
<td>43.1 ±7.0</td>
<td>39.0 ±5.2 [p=0.013 (CI 1.0 – 7.9)]</td>
</tr>
</tbody>
</table>

Abbreviations: FITS, finger tapping speed; FoTS, foot tapping speed; dig, digit; SD, standard deviation; R, right side; L, left side; CI, confidence interval

Data are given as means ± SD, unless indicated otherwise. Statistical significant differences between males and females are based on Student’s t-test for independent samples (p-values and CI in superscript).
DISCUSSION

Firstly, our study showed that measuring FiTS and FoTS visually, without any device to register the number of taps such as (mouse) buttons, keyboards, or electronic, infrared or magnetic sensors was reliable. All that is needed is either a stopwatch (operated by a second person), or an audiotape providing start and stop commands, enabling the investigator to focus on counting. Secondly, we provided normative values for FiTS and FoTS for 5 age groups, ranging from 21-30 years to 61-70 years. In the following paragraphs, we compare our findings to those from previous studies.

Reliability of FiTS and FoTS

There are no data at hand on reliability of the measurement of FiTS or FoTS without the use of devices. A study using a computerized dynamometer to count FiTS reported an intrarater reliability of $r=0.97$ ($p<0.001$) and an interrater reliability of 0.99 ($p<0.001$), as analysed with the Pearson’s correlation coefficient. Another study found a good interrater reliability and test-retest reliability for FiTS using a mechanical counter. However we cannot compare these data with ours as only reliability data for a series of four tests of arm/hand function are given in their study and not data solely concerning FiTS.

FiTS

In this study, agreement of FiTS by both raters with FiTS by the gold standard was good (ICC>0.8), although in session 1 agreement with rater 2 was better than agreement with rater 1. The same held true for the interrater agreement, which improved in session 2. The Bland-Altman plots showed for FiTS in session 1 that agreement between both raters diminished when tapping speed was faster. Agreement of FiTS by rater 1 with the gold standard and with rater 2 improved in the second session which may imply a learning effect for rater 1. This learning effect seemed to affect mainly measurements of very high tapping speed. The Bland-Altman plot of FiTS in session 2 showed no tendency for a decrease in agreement with increasing FiTS. Therefore we advise to observe two trials of tapping, and use values of the second trial.

FoTS

Agreement of FoTS between both raters was good, as well as agreement of both raters with the gold standard. The Bland-Altman plots of both sessions did not show decreased
agreement with increased tapping speed. In contrast to FiTS, we did not observe a learning effect in either of the raters measuring FoTS. This may be related to the fact that FoTS in general is somewhat slower than FiTS.

**Normative values**

**Effects of age**

Many studies found an inverse correlation between age and FiTS. We observed a non-linear inverse correlation between FiTS and age which is in line with previous studies. FoTS was in general not significantly influenced by age. Studies on normative values for FoTS and relation with age are lacking. However, it was demonstrated that fine motor skills are more affected by age than course motor skills, which may be an explanation for our finding.

**Effects of dexterity**

Previous studies found a correlation between dexterity and FiTS, the dominant index finger tapping faster than the contralateral one. Our study largely confirms these findings. All but 1 of the 46 right-handed individuals tapped faster with their dominant hand. We included only 4 left-handed individuals in this study, 2 of them tapping faster with their right index finger. Although these are very low numbers, it may be hypothesized that some of the left-handed individuals were in fact ambidexter. Also, left-handed individuals have often learned to use their right hand as many utensils are shaped for right-handed individuals.

Studies on the correlation of dexterity and FoTS are lacking. We found no correlation between FoTS and dexterity. An explanation for this finding may be that motor asymmetry is stronger and more manifest for handedness than for footedness.

**Effects of gender**

In contrast to other studies we did not find a significant difference of FiTS between males and females. However, our study differ substantially from others with regard to methodology of tapping tasks, which hampers comparison. FoTS in females was significantly slower than in males. Studies on effects of gender on FoTS are lacking.

**Clinical use of FiTS and FoTS**

FiTS and FoTS are parameters that can easily be used in longitudinal studies involving patients with upper motor neuron disease or movement disorders. In a study that we
performed in patients with motor neuron disease we already showed that FITS proved more accurate to differentiate patients from controls than did MRS parameters. Furthermore, previous studies stated that pyramidal slowness can be distinguished from parkinsonian slowness. In primary lateral sclerosis patients and stroke patients, pyramidal slowness resulted in a slow FITS without fatiguing or decrement. However, in patients with parkinsonian syndromes, fatiguing and decrement were evident. In our study, we did not address this difference between slowness based on compromised pyramidal tracts or extramotor involvement like in movement disorders. However, in the context of clinical evaluation of a patient with suspected upper motor neuron disease or a movement disorder, we believe that FITS and FoTS may well be effective tools to help define which extremities are involved in the disease process. Furthermore, as FITS and FoTS are continuous variables, they may be of use in monitoring disease progression over time. Future studies investigating the decrease of tapping speed with increasing age within healthy individuals would be of value.

CONCLUSION

This study demonstrates that measurement of FITS and FoTS without the use of devices is reliable. In individuals with a very high tapping speed reliability may be of influence on interrater agreement. We found a significant inverse relation between age and FITS. Dexterity influences FITS strongly. Therefore, the finding of FITS being slower in the dominant hand may be suggestive of pyramidal or extrapyramidal pathology.
REFERENCES


