Standardization of a neuromotor test battery: The CATSYS System

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ABSTRACT

Interindividual and intraindividual variability in neuromotor behaviors is expected and normal. Early changes in neuromotor behaviors associated with neurodegenerative disorders or neurotoxic effects are often subtle and fluctuating in their characteristics. Therefore, their detection at an early stage is particularly difficult without precise recording instruments. The CATSYS system developed by Danish Product Development (DPD) is a portable device recording four measures of neuromotor control including tremor, reaction time, hand coordination and postural sway. The aim of this study is to develop a set of normative data. One hundred and fifty healthy men and women were divided into five age groups: (1) 20 to 29 years (n=30); (2) 30 to 39 years (n=30); (3) 40 to 49 years (n=30); (4) 50 to 59 years (n=30); (5) 60 to 70 years (n=30). All participants were free of neurological deficits at the time of testing and they were tested individually for approximately 30 min. Hand coordination was measured with prono-supination and finger-tapping movements executed at constant and accelerated rhythms. Reaction time was assessed in both hands using a hand held switch activated by the thumb. Postural tremor was quantified in both hands during 24.6 sec. by asking the subject to hold a stylus horizontally at 10 cm in front of his/her navel. The stylus contained a biaxial accelerometer. Postural sway was tested by asking the subject to stand on a force platform for 75 sec. under four conditions: (1) eyes open; (2) eyes closed; (3) eyes open standing on a foam pad; and (4) eyes closed standing on a foam pad. ANOVAs and multiple comparison tests were performed and the results were examined taking into account age, gender and experimental condition effects.

Running head: Standardization CATSYS System.

Keywords: DPD system, CATSYS System, standardization, motor tests, tremor, postural sway, manual coordination.

INTRODUCTION

Few neuromotor tests batteries allow a complete and easy evaluation of sensorimotor functions. Danish Product Development has developed DPD system 7.0 in Denmark in 1992. It is a portable system composed of three tests: Coordination Ability Test System, Tremor Analysis Test System and Sway Analysis Test System. This computerized battery is designed for quick and precise assessment of different motor performances (manual coordination, reaction time, tremor and postural sway).

Maintenance of standing posture, manual coordination and tremor have long been associated with assessment of nervous system functions. Many studies have evaluated these functions to detect neuromotor modifications after neurotoxic exposure (Neterstrom *et al.*, 1996; Dick *et al.*, 1990; Kuo *et al.*, 1996; Chia *et al.*, 1993). One advantage associated with the use of a quantitative sensorimotor test battery is the reduction of subjectivity often observed with clinical scales. Therefore, the results, which are objective, can be used to make interpretations of the performance based on well-established facts. The quantification of subtle impairments in human motor functions is useful for clinicians as well as for researchers. This clinical tool has several applications: it can be useful for diagnosing and supervising patients suffering from neurological diseases, for screening individuals, for quantifying effects of drugs or for detecting abnormalities caused by neurotoxic substances.

In recent years, some researchers have evaluated this electronic equipment. An evaluation of the Tremor pen has been performed by Edwards & Beuter (1997) and by

Orsnes & Sorensen (1998). Using CATSYS and Tremor systems, Netterstrom *et al.* (1996) found that quantification of coordination ability and tremor intensity could be useful for assessment of the impact of acute mercury intoxication.

As expected, interindividual and interindividual variability in neuromotor behaviors are perfectly normal. Sometimes, enhanced physiological tremor or modifications of postural sway are normal fluctuations over time, which can be associated with several factors (fatigue, anxiety, etc.). However, to detect disturbances of nervous system or sub-clinical signs of pathology, standards are needed to compare the results to human normality (to sex- and age-matching control groups).

Using CATSYS system, Gyntelberg *et al.* (1990) presented normal values in adults aged between 15 to 60 and they found a high degree of reproducibility for the tests used. However, the population was exclusively women and only coordination abilities were evaluated. In fact no known studies have standardized the whole battery system. The standard presented by the manufacturer of the test battery is valid only when the specifications for testing are matched. Because we have introduced new calculation methods for tremor measures and added experimental conditions to sway testing, we had to establish a new standard in order to compare future findings to corresponding normality. The aim of this study is to develop a set of normative data based on new test conditions for postural sway and also to illustrate some improvements that we have made to the calculation of certain tremor characteristics (Tremor Index and Harmonic Index) (Edwards & Beuter, 1999). In addition, because of probable modification of performance with age, the new standardization will include five groups of individuals aged between 20 and 70 years. These new standards will allow more flexibility in how to assess test conditions for different characteristics of sensorimotor functions, as well as permitting more precision in the comparison of matching control groups.

MATERIALS AND METHODS

Subjects

In order to reach a large population, several recruitment methods have been used: ads in newspapers and in different public institutions in Montreal areas (local community services centres, retirement residences, supermarkets, and universities). A total of 162 individuals agreed to participate in the study. A phone questionnaire concerning health state was first administered in order to eliminate non-healthy participants. Exclusion criteria were head trauma, epilepsy, Parkinson's disease, Alzheimer's disease, multiple sclerosis, alcohol or drug dependency. Of the 162 subjects, 4 subjects had to be rejected from the study due to alcoholic consumption or drug addiction. Five others were rejected because of cardiac problems, pathologic obesity or finger amputation. Finally, post hoc exclusions included suspected alcoholism (n=2) and suspected drug dependency (n=1).

One hundred and fifty healthy men and women aged between 20 and 70 were selected for the study. All of these participants were free of neurological deficits or known disease at the time of testing. The subjects were placed in the corresponding groups according to the category of their age and gender until each group reached a total of 15 subjects. Therefore, women and men were equally divided in respect to the age groups: (1) 20 to 29 years (n=30), (2) 30 to 39 years (n=30), (3) 40 to 49 years (n=30), (4) 50 to 59 years (n=30), (5) 60 to 70 years (n=30). To make our sample representative of the population, an effort was made to recruit individuals of various sociodemographic characteristics (age, sex, language, usual occupation, level of education, ethnic origin, etc.). Table 1 presents some of the sample characteristics.

Please insert Table 1

Two experimenters were trained to administer the tests. They first obtained a written informed consent and then, administered a pretest questionnaire. Information was gathered on age, occupation, smoking habit or coffee consumption. Alcohol intake on the day of testing was also documented carefully as it could confound the findings.

Equipment and test procedures

The DPD system developed by Danish Product Development has been used to record different neuromotor functions including tremor, reaction time, hand coordination and postural sway. The study was conducted in a quiet room and subjects were tested individually. All participants followed the same sequence of tests that lasted approximately 30 minutes.

Hand coordination

Manual coordination was examined with the CATSYS Test System, which is composed of a drum that records hand pronation-supination and finger-tapping movements, and a hand held switch measuring reaction time. All tests were performed with right and left hands under five standard conditions: 1) Hand pronation-supination at a constant slow (1 Hz) and a constant fast (2.5 Hz) metronome beat; 2) Hand pronation-supination at an accelerating rhythm (from 1.6 Hz to 7.5 Hz); 3) Finger tapping at a constant slow (1 Hz) and a constant fast (2.5 Hz) beat; 4) Finger tapping at an accelerating rhythm (from 1.6 Hz to 8.1 Hz); 5) Reaction time to a sound stimulus.

We built a holder (support) made of foam in which we inserted the drum in order to increase the stability of the drum when the subject is doing the different tasks (finger tapping or pronation-supination). When the subject was performing pronation-supination task with one hand, he or she held the support with the other hand and so the apparatus is very stable. Also, this holder is the same height as the drum. Thus, for the finger tapping tasks, it brings the wrist, hand and fingers into a neutral position. Without this support, the index finger is hyperextended and this position is not comfortable for the subject.

Several parameters were calculated from the results: Rhythmic Regulation S(P) to keep up Precision (P) on slow, fast or accelerated metronome beat, Maximum Frequency obtained (MF), and Reaction Time (RT). Table 2 presents the definitions of these terms.

Please insert Table 2

Postural tremor

Postural tremor was measured successively for each hand during 24.6 sec. by asking the subjects to hold a light stylus (Tremor® Pen) as they would hold an ordinary pen, with the elbow joint bent at a right angle and free of body contact or any obstacles. The stylus was held horizontally, parallel to the abdomen at approximately 10 cm in front of the navel and the index finger was positioned approximately 1 cm from the tip of the stylus. During the recording, subjects were asked to look at the tip of the stylus, breathe normally and relax.

The stylus (12 cm X 0.8 cm) contained a biaxial micro-accelerometer and is sensitive in a plane perpendicular to the tube axis. The hand vibrations were recorded and displayed in real-time on a time axis plot on the computer screen. Fast Fourier transform (FFT) analysis determines the normalized power distribution of the tremor in the frequency band 0.9 Hz to 15.0 Hz. Measures derived from acceleration data are based on the Fourier power. Five key figures were calculated: Tremor Intensity (I), Centre Frequency (F50), Standard Deviation of Centre Frequency (SF50), Harmonic Index (HI) and Tremor Index (TI). A short definition of each term is specified in Table 3.

Please insert Table 3

Postural sway

The Sway Analysis Test System is a platform containing 3 orthogonal strain-gauge devices. Postural sway was tested by asking the subjects to stand on the platform, feet at 1 cm apart, with their arms at their sides, the body slightly tilted forward with a good support on the balls of their feet. Subjects were asked to look at a picture placed at around 2 meters in front of them, or to keep their eyes closed. These tasks were performed with or without a pad of polystyrene foam (2 cm thick) under their feet.

For each subject, postural sway was measured for 75 sec. (standard test procedure: 10 sec. start-up period, 60 sec. recording period and 5 sec. run-out period) in the following sequence: (1) Eyes open and (2) Eyes closed, standing directly on the platform; (3) Eyes open, and (4) Eyes closed, standing on the platform with a soft foam (2 cm thick) under their feet. The foam used is made of porous polystyrene (standard foam used for camping). We also drew a line (1 cm thick) on the platform and on the foam in order to control the position of the feet for each condition.

Sway parameters calculated from each subject's performance include: Mean-Sway (MS), Transversal Sway (TS, x-direction), Sagittal Sway (SS, y-direction), Sway Index (SI), Sway Area (SA), and Sway Velocity (SV). Table 4 gives a brief definition of these terms.

Please insert Table 4

Data treatment and analysis

DPD power spectrum data in CATSYS format have been converted to ASCII format for data treatment. Some modifications in calculation methods of the DPD Harmonic Index (HI_{DPD}) and the DPD Tremor Index (TI_{DPD}) have been performed. A transformation of the HI_{DPD} has been performed to rectify the asymmetry of its distribution with the aim of increasing the discrimination power on the right side of the distribution. This modified HI (HI_{new}) corresponds to -log (1-HI_{DPD}). Our Tremor Index (TI_{new}) is the RMS of the z-scores of the four measures**.** This squared z-scores is counted twice as done in the original calculation of the TI_{DPD}. Of course, in this recalculated TI_{new}, we use the transformed HI_{new}. Our calculation improves the sensitivity in the tails of the distribution by avoiding the transformation ($e^{-|z|}$) used in the TI_{DPD}. These improvements are explained in detail in Edwards & Beuter (1999).

Because of the inherent goal of this study, both descriptive and statistical analyses have been performed. In most cases, statistical analyses were performed in order to evaluate the significance level of our observations. Statistical analyses were done using ANOVAs and multiple comparison tests, taking into account the age, gender, experimental condition effects (for postural sway) and differences between the two hands (for tremor and manual coordination). Frequency distributions and means for each of the variables of interest were examined. Tables 5, 6 and 7 summarize the results for manual coordination, postural tremor and postural sway respectively[1].

RESULTS

Manual coordination: (Table 5)

[1] Detailed results tables can be consulted at our WEB site: www.er.uqam.ca/nobel/r11040/index.htm.

-Age effect

Reaction time: There was no obvious or significant effect of age on Reaction Time.

Finger tapping: No differences were observed for the finger-tapping task at slow cadence. In contrast, at fast cadence, we observed that the Precision for the right hand varies significantly with age (f = 3.600, p <0.008). A multiple comparison test showed that the difference was mainly for the younger group (20-29) that showed more precision than the older groups (50-59 and 60-69). This was not observed for the left hand. Precision analysis for the Maximum Frequency task when performed with the right hand showed that there was a significant difference between age groups (f = 3.167, p<0.016). Participants aged between 20-29 were more precise than participants aged between 50-59. Rhythmic Regularity S(P) also varied significantly with age (f = 4.929, p<0.001). The difference was mainly between the younger group (20-29) that showed less variation while following the rhythm than the 50-59 and 60-69 age groups. Rhythmic Regularity S(P) for the left hand when performed at Maximum Frequency task also showed significant differences (f = 5.460, p<0.000) but the differences were observed between the 30-39 age group and both the 50-59 and 60-69 age groups.

Pronation-supination: Rhythmic Regularity S(P) for the pronation-supination task at slow cadence showed a significant age effect for the right hand (f = 5.187, p<0.001) and for the left hand (f = 5.448, p<0.000). The difference was mainly between the younger group (20-29) that showed more precision than the older groups (50-59 and 60-69).

-Gender effect

Reaction Time: We observed a significant difference between men and women for the right hand ($f = 8.401$, $p < 0.004$) and for the left hand ($f = 10.995$, $p < 0.001$) showing that men were slightly faster than women for this task.

Finger tapping and pronation-supination tasks: When performing qualitative analysis, men obtained several higher results (but not statistically significant) for Maximum Frequency (MF) tests.

-Right-left differences:

For the pronation-supination movements, we observed some significant differences for the Maximum Frequency (MF) ($t = 2{,}033$, $p < 0{,}044$) where the scores for the right hand were higher than the scores for the left hand. A significant difference was also observed for the Precision (P) ($t = 3{,}574$, $p < 0{,}000$) and Rythmic Regulation (S(P)) ($t = -3{,}556$, $p < 0{,}001$) whereas the performance of the right hand was better than the performance of the left hand.

For the finger tapping movements, a significant difference was observed for the Precision ($t = 2{,}716$, $p < 0{,}007$) and the Maximum Frequency measures ($t = 2{,}850$, $p < 0{,}005$) where the right hand obtained better results than the left hand.

Please insert Table 5

Tremor: (Table 6)

-Age effect: Centre Frequency tended to decrease with age for men and women and for both hands. For this measure, the 60-69 age group obtained the lowest results for both hands. We observed a significant age effect for Centre Frequency (F50) for both the right hand ($f = 4.070$, $p<0.004$) and the left hand ($f = 6.451$, $p<0.005$). Multiple comparison tests showed that the main effect was between participants in the younger groups (20-29 and 30-39) and participants in the older group (60-69). Harmonic Index (HI) tended to increase with age for men and women and regardless of which hand was used. This trend reached significance level for both the right hand (f = 17.963, p<0.000) and the left hand (f = 3.147, p<0.016). Finally, Intensity, Frequency dispersion and Tremor Index did not differ significantly with age for both gender and both hands.

-Gender effect: For most of the age groups and for both hands, Tremor Index (TI), Centre Frequency (F50), Standard Deviation of Centre Frequency (SF50) and Intensity (I) were slightly higher for men than for women. Although trends were observed, no statistically significant difference was noted.

-Right-left differences: The right hand obtained higher results than the left hand for the Intensity (t = 7,094, p < 0,000) and for the Harmonic Index (t = 7,540, p < 0,000). Frequency dispersion (SF50) is higher for the left hand than for the right hand (t = -9,597, p < 0,000)

Please insert Table 6

Postural sway: (Table 7)

-Age effect: Postural sway significantly increased with age for Mean Sway (f = 2.626, p< 0.031), Sway Area (f = 4.324, p<0.002) and Sway Velocity (f = 7.443, p< 0.000). The increase was gradual with age for all experimental conditions.

-Gender effect: Postural sway for men was higher than for women in all of the characteristics, except for Sagittal Sway where the results were not significant. (Mean Sway (f = 4.667, p<0.031), Transversal Sway (f = 11.386, p<0.001), Sway Index (f = 4.603, p<0.032), Sway Area (SA) (f = 7.119, p<0.008), Sway Velocity (f = 32.261, p< 0.000).

-Experimental conditions effect: A significant increase of postural sway in all of the characteristics was observed for men and women of all age groups throughout the four experimental conditions: Mean Sway ($f = 28.916$, $p<0.000$), Transversal Sway ($f = 33.334$, $p<0.000$), Sagittal Sway ($f = 15.084$, $p<0.000$), Sway Index ($f = 2.085$, $p<0.000$), Sway Area ($f = 43.583$, $p<0.000$) and Sway Velocity ($f = 70.139$, $p<0.000$). For Sway Velocity, higher results were obtained with eyes closed (conditions 2 and 4) than with eyes open (conditions 1 and 3). Sway Area tended to react also in the same way to these conditions but the effect was not statistically significant.

Please insert Table 7

DISCUSSION

Manual coordination:

It is interesting to note that men performed better than women on tests that require speed (eg. Maximum Frequency tests and Reaction Time). Tests that demand precision and rhythm were executed similarly by both genders. As expected the right hand was faster, more precise and less variable for the Maximum Frequency tasks.

It is important to note that there was a lot of variation between individuals for these tests. Because of this important intersubject variability, even with healthy subjects, it is therefore difficult to define clearly what is considered a normal or an abnormal performance. We have noticed that some people are more familiar with rhythms (eg. musicians) and thus perform better. This is related to the rhythmical constraint imposed by the tasks. Of course, less ability to follow an imposed rhythm correctly would not necessarily reflect an underlying dysfunction.

We noted some limitations of the drum for the pronation-supination task. The system only records the contacts of the hand on the drum. Between the contacts, the movement of the hand in the air is not recorded. By doing so, there is a lot of important information not recorded (often important in dyskinesias or other movement disorders). Moreover, the drum records just one hand at a time and bimanual coordination cannot be evaluated. An alternative solution for these problems is to use other apparatus that measure diadochokinesia with optical encoders (Beuter *et al.*, 1999).

Tremor:

In this study, we have prolonged the tremor test length from 8.2 sec. (standard length) to 24.6 sec. (three times longer). An increase of reproducibility and fidelity is therefore expected with these longer tests. It also provides more precision for statistical analysis (spectrum and other measures) and thus decreases the variance of the measures. So, we expect to get more power when discriminating two groups. Moreover, because pathological manifestations of tremor are sometimes intermittent (eg. Parkinson's disease), a longer time test increases the probability to observe a transition from off to on state. Even if we do a 24.6 seconds recording, we do not have to worry about fatigue because we consider it negligible for such a short recording period.

The fact that Harmonic Index tended to increase with age, but that Centre Frequency and Frequency dispersion tend to decrease with age means that tremor becomes more regular and slower in frequency with age. Modifications of frequencies with age are also noted by Marsden *et al.* (1969) and Wade *et al.* (1982). Most subjects showed a tremor pattern characterized by several peaks. Wade *et al.*, (1982) also noted this complex spectral pattern. This observation means that normal tremor is generally variable in frequency and not organized around a single frequency. Results obtained for the right-left differences mean that the right hand was less variable, more regular and showed a higher amplitude. Slight differences between the two hands were expected and seen in other studies (Orsnes *et al.*, 1998).

It is important to note that because of the modification done to the Tremor Index and the Harmonic Index, normal performance according to the 61 subjects in the manual of the CATSYS system (Heeboll, J., 1994), must be reconsidered. In that respect, the new performance values for Harmonic Index are presented in Table 8. As for the Tremor Index, the new standard value according to the 61 subjects is 1.55 for both hands combined. This could be uses as a threshold value, therefore, above which there is a small probability of the tremor being normal. This value corresponds to the 95th percentile (Edwards & Beuter,1999).

Please insert Table 8

Postural sway:

The effect of age on postural sway was observed in our sample. Other studies have also noted an increase of body sway with age (Perrin *et al.* 1997). The fact that men obtained higher results than women can be explained by their proportionally higher morphological characteristics (height and weight). Higher height brings their centre of mass higher than women, and therefore can cause more oscillation. This phenomenon is discussed in Kuo *et al*. (1996). However, this observation is not supported by Hageman *et al*. (1995).

These four experimental conditions were designed to challenge the different roles played by vision (eyes open or closed) and proprioception (with or without foam) and the vestibular system. Effectively, the consequences of these factors on postural sway have been revealed clearly in this study. The increase of postural sway with increase of task difficulty (from condition 1 to condition 4) was observed for all postural sway characteristics. In particular, the fourth condition produced an important increase in postural sway for men and women of all age groups. This last condition caused the most unbalancing effect. The role of visual input has been noted by Perrin *et al.* (1996) and Brouwer *et al.* (1998).

Sway Velocity seems to be the characteristic most sensitive to age. On this characteristic, the group 60-69 obtained a higher result for each experimental condition. Sway Velocity seems to be very sensitive to visual input. For this characteristic, postural sway was higher with eyes closed (conditions 2 and 4) than with eyes open (conditions 1 and 3). Ishizaki *et al.* (1991) stated that sway velocity is thought to be the most effective parameter reflecting the postural control system. In a study evaluating the acute effect of ethanol, Letz *et al.* (1995) also observed that sway speed was the most sensitive and reliable measure of several summary measures of standing steadiness.

However, it is important to note that some standard deviations were very large, particularly for Sway Area. Hence, there was a lot of variation in interindividual performances. Other studies have also reported a wide range of individual differences in sway parameters (Dick *et al.*, 1988). The variability is often so important that Brouwer *et al.* (1998) stated that data evaluated in relation to a standard normative database may introduce biases in the assessment.

CONCLUSION

The use of a computerized measurement system may be a good way to assess neuromotor functions objectively and precisely. However, standards are needed to compare results to normality and are helpful in assessing neurological impairments caused by diseases of the central nervous system (such as Parkinson's disease) or by exposure to neurotoxic substances (such as mercury or manganese). This standardization provides a reliable estimate of normal interindividual variability as well as intraindividual variability. Though some problems were observed with manual coordination using the drum (particularly with pronation-supination), we think that there is a need for such a motor battery.

These results will be most helpful in single case studies or when the effects of age or gender need to be estimated in North American populations. This study is also used to illustrate some of our improvements to the calculation of tremor parameters proposed by DPD. We hope that this new standardization and these modifications will be included in a revision of CATSYS system manual.

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Table 1: Demographic data for 150 subjects

Age (group)	Variable (units)	Mean	SD	Minimum	Maximum
20-29 years	Age	24.5	2.7	20	29
	Weight	68.87	13.17	43.19	103.70
	Height	1.77	0.075	1.55	1.90
30-39 years	Age	33.9	2.9	30	39
	Weight	65.46	11.96	42.4	84.9
	Height	1.70	0.079	1.60	1.88
40-49 years	Age	43.7	2.7	40	49
	Weight	72.3	14.06	45.3	101.7
	Height	1.71	0.097	1.54	1.98
50-59 years	Age	53.2	2.6	50	59
	Weight	64.29	11.81	46	91
	Height	1.65	0.096	1.47	1.78
60-70 years	Age	65.1	2.9	60	70
	Weight	72.9	16.3	38.3	118.1
	Height	1.64	0.085	1.42	1.78
20-70 years	% smokers		21% (women: 15% men: 6%)		
	% coffee drinkers		66% (women: 37% men: 29%)		
	% left-handers		9% (women: 6% men: 3%)		

Table 2: Definition of the specific parameters examined for **coordination abilities**

Parameters	**Definition**
Catsys Index (CI)	An overall performance index calculated as a simple mean of up to 10 performance indices (PI), multiplied with 100.
Performance indices (PI)	Performance indices are calculated by comparing the test performance with mean values from a large population.
Rhythmic regulation (s(P))	Rhythmic regulation to keep up precision
Precision (P)	Accuracy of contact in relation to metronome sound .
Maximum frequency (MF)	Maximum frequency obtained.
Reaction time (RT)	Mean of all reaction time obtained during the test

Table 3: Definition of the specific parameters examined for the **tremor**

Parameters	**Definition**
Tremor Intensity (I) or amplitude Unit: m/s^2	The root mean square (RMS) of acceleration recorded in the 0.9-15 Hz band. Larger values indicate more tremor.
Centre Frequency (F50) Unit: Hz or s^{-1}	The median frequency of the acceleration in the 0.9-15 Hz band: 50% of the area under the spectrum is at frequencies above the centre frequency and 50% is below.
Frequency dispersion (SF50) Unit: Hz	Degree of irregularity of the tremor. Frequency band centred around the medium frequency, which contains 68% of the power. A regular tremor has a small SF50 indicating that most of the area is within a narrow frequency band (e.g.: pathological tremors).
Harmonic Index (HI)	Compares the tremor frequency pattern with the pattern of a single harmonic oscillation, which has a HI = 1.00. HI decreases when the tremor is composed of many oscillations.
Tremor Index (TI)	An overall summary index, which incorporate the four previous measures. Any value deviating significantly from the norm will contribute a smaller than usual amount to the TI.

Table 4: Definition of the specific parameters examined for the **postural sway**

Parameters	**Definition**
Mean Sway (MS)	Simple mean of the distance from the mean force centre position (FCP) to all recorded force centre positions during the test.
Transversal Sway (TS)	Simple mean of the recorded x-direction values of the force centre in a coordinate system.
Sagittal Sway (SS)	Simple mean of the recorded y-direction values of the force centre in a coordinate system.
Sway Index (SI)	Relates the sway test result to human normal sway established by the manufacturer.
Sway Area (SA)	Area of the smallest polygon, which includes the total trajectory of the force centre in the horizontal plate plane.
Sway Velocity (SV)	Average travel speed of the force centre in the horizontal sway plate plane calculated by dividing the total length of the force centre trajectory (in mm) by the recording period length (in sec.).

Table 5: Summary of results for manual coordination test

Catsys 7.0 Statistics

		Men and women 20-29(n=30)		**Men and women 30-39**(n=30)	
Tests	Abb	Left hand	Right hand	Left hand	**Right hand**
Rhythmic P/S	Ps, S(Ps) Pf, S(Pf)	-0.058 (0.045) -0.015 (0.031)	-0.034 (0.039) -0.028 (0.028)	-0.067 (0.050) -0.025 (0.030)	-0.031 (0.050) -0.035 (0.034)
Rhythmic FT	Ps, S(Ps) Pf, S(Pf)	-0.038 (0.044) -0.021 (0.034)	-0.056 (0.060) -0.022 (0.029)	-0.048 (0.055) -0.043 (0.039)	-0.048 (0.053) -0.040 (0.035)
Max. Freq. P/S	MF P, S(P)	4.5 -0.001 (0.031)	4.6 0.007 (0.030)	4.1 -0.003 (0.035)	4.3 0.001 (0.028)
Max.Freq. FT	MF P, S(P)	5.4 -0.007 (0.027)	5.8 -0.008 (0.029)	5.4 -0.012(0.034)	5.5 -0.006 (0.028)
R. time	RT, S(RT)	0.209 (0.032)	0.208 (0.037)	0.210 (0.038)	0.203 (0.034)
		Men and women 40-49(n=30)		**Men and women 50-59**(n=30)	
Tests	Abb	Left hand	Right hand	Left hand	Right hand
Rhythmic P/S	Ps, S(Ps) Pf, S(Pf)	-0.081 (0.047) -0.018 (0.037)	-0.057 (0.056) -0.029 (0.036)	-0.073 (0.067) -0.019 (0.047)	-0.039 (0.066) -0.034 (0.043)
Rhythmic FT	Ps, S(Ps) Pf, S(Pf)	-0.039 (0.048) -0.015 (0.030)	-0.034 (0.047) -0.037 (0.035)	-0.045 (0.042) -0.020 (0.031)	-0.042 (0.043) -0.050 (0.034)
Max. Freq. P/S	MF P, S(P)	4.5 -0.004 (0.031)	4.6 0.004 (0.030)	3.7 -0.002 (0.035)	4.2 0.005 (0.035)
Max.Freq. FT	MF P, S(P)	5.1 -0.007 (0.039)	5.5 -0.008 (0.029)	5.0 -0.012 (0.034)	5.3 -0.008 (0.033)
R. time	RT, S(RT)	0.213 (0.039)	0.207 (0.042)	0.219 (0.037)	0.217 (0.042)
		Men and women 60-70(n=30)		**Men and women 20-70**(n=150)	
Tests	Abb	Left hand	Right hand	Left hand	Right hand
Rhythmic P/S	Ps, S(Ps) Pf, S(Pf)	-0.064 (0.061) -0.034 (0.042)	-0.043 (0.062) -0.044 (0.039)	-0.037 (0.045) -0.010 (0.033)	-0.019 (0.035) -0.025 (0.021)
Rhythmic FT	Ps, S(Ps) Pf, S(Pf)	-0.033 (0.051) -0.040 (0.038)	-0.035 (0.057) -0.056 (0.031)	-0.042 (0.049) -0.016 (0.030)	-0.040 (0.051) -0.021 (0.029)
Max. Freq. P/S	MF P, S(P)	4.3 -0.008 (0.034)	4.6 -0.003 (0.033)	4.3 0.002 (0.034)	4.4 0.011 (0.024)
Max.Freq. FT	MF P, S(P)	5.3 -0.015 (0.032)	6.0 -0.014 (0.031)	5.3 -0.009 (0.028)	5.7 0.001 (0.026)
R. time	RT, S(RT)	0.203 (0.035)	0.198 (0.034)	0.201 (0.032)	0.197 (0.039)
		Women 20-70 (n=75)		**Men 20-70** (n=75)	
Tests:	Abb	Left hand	Right hand	Left hand	Right hand
Rhythmic P/S	Ps, S(Ps) Pf, S(Pf)	-0.061 (0.052) -0.024 (0.036)	-0.040 (0.053) -0.038 (0.038)	-0.076 (0.056) -0.020 (0.038)	-0.042 (0.055) -0.030 (0.033)
Rhythmic FT	Ps, S(Ps) Pf, S(Pf)	-0.044 (0.053) -0.024 (0.038)	-0.051 (0.058) -0.041 (0.033)	-0.037 (0.042) -0.032 (0.031)	-0.036 (0.046) -0.041 (0.033)
Max. Freq. P/S	MF P, S(P)	4.3 -0.002 (0.032)	4.4 0.004 (0.031)	4.4 -0.005 (0.035)	4.5 0.000 (0.030)
Max.Freq. FT	MF P, S(P)	5.1 -0.008 (0.031)	5.5 -0.005 (0.029)	5.4 -0.013 (0.029)	5.8 -0.009 (0.030)
R. time	RT,S(RT)	0.210 (0.039)	0.215 (0.039)	0.201 (0.034)	0.199 (0.036)

P: Precision, S(P): Rhythmic Regularity, s: slow cadence, f: fast cadence

Table 6: Summary of results for postural tremor test

TREMOR 7.0 Statistics								
	Men and women 20-29 (n=30)				**Men and women 30-39** (n=30)			
	Left hand		Right hand		Left hand		Right hand	
Characteristics	K_m	$s(K_m)$	K_m	$s(K_m)$	K_m	$s(K_m)$	K_m	$s(K_m)$
TI*	1.20	0.36	1.06	0.36	1.16	0.38	1.02	0.35
I (m/s$^{2)}$	0.13	0.04	0.12	0.03	0.12	0.04	0.13	0.03
F50 (Hz)	7.4	1.22	7.1	0.88	7.4	1.04	7.3	0.75
SF50 (Hz)	3.11	0.54	3.04	0.54	2.92	0.53	2.53	0.49
HI*	1.60	0.33	1.62	0.27	1.69	0.49	1.76	0.33
	Men and women 40-49 (n=30)				**Men and women 50-59** (n=30)			
	Left hand		Right hand		Left hand		Right hand	
Characteristics	K_m	$s(K_m)$	K_m	$s(K_m)$	K_m	$s(K_m)$	K_m	$s(K_m)$
TI*	1.08	0.33	1.11	0.39	1.18	0.48	1.36	0.66
I (m/s$^{2)}$	0.11	0.04	0.13	0.03	0.11	0.04	0.13	0.05
F50 (Hz)	6.9	1.04	6.9	0.86	7.0	0.86	7.1	0.64
SF50 (Hz)	3.23	0.45	2.49	0.66	2.73	0.71	2.08	0.58
HI*	1.85	0.40	2.12	0.52	1.95	0.41	2.46	0.44
	Men and women 60-70 (n=30)				**Men and women 20-70** (n=150)			
	Left hand		Right hand		Left hand		Right hand	
Characteristics	K_m	$s(K_m)$	K_m	$s(K_m)$	K_m	$s(K_m)$	K_m	$s(K_m)$
TI*	1.09	0.27	1.12	0.33	1.14	0.37	1.13	0.45
I (m/s$^{2)}$	0.11	0.03	0.13	0.03	0.11	0.04	0.13	0.03
F50 (Hz)	6.5	0.83	6.5	0.73	7.06	1.05	6.98	0.81
SF50 (Hz)	3.16	0.54	2.36	0.56	3.03	0.58	2.50	0.64
HI*	1.96	0.45	2.26	0.45	1.77	0.43	2.08	0.50
	Men 20-70 (n=75)				**Women 20-70** (n=75)			
	Left hand		Right hand		Left hand		Right hand	
Characteristics	K_m	$s(K_m)$	K_m	$s(K_m)$	K_m	$s(K_m)$	K_m	$s(K_m)$
TI*	1.19	0.41	1.23	0.51	1.10	0.32	1.04	0.35
I (m/s^2)	0.13	0.04	0.14	0.04	0.10	0.03	0.12	0.03
F50 (Hz)	7.26	1.09	7.07	0.84	6.85	0.97	6.88	0.77
SF50 (Hz)	3.10	0.62	2.51	0.69	2.95	0.54	2.49	0.59
HI*	1.74	0.43	2.07	0.50	1.80	0.44	2.10	0.50

K_m: Key number

$s(K_m)$: Standard deviation of key number

*Recalculated (see section Data treatment and analysis)

Table 7: Summary of results for postural sway test

Men (20 to 70 years) n=75												
	Mean sw. (mm)	S(Ms)	**Trans (mm)**	S(Ts)	**Sagit (mm)**	S(Ss)	**Sw. Index**	S(Si)	**Sw. Area (mm^2)**	S(Sa)	**Sway vel. (mm/s)**	S(Sv)
Sway 1	6.21	1.98	3.44	0.93	4.40	1.85	152.47	37.77	368.19	220.82	12.23	3.79
Sway 2	6.67	1.81	4.23	1.54	4.22	1.17	146.88	36.45	506.17	280.35	16.20	5.71
Sway 3	7.44	2.07	4.56	1.58	4.90	1.66	129.57	44.38	481.00	259.85	12.84	3.99
Sway4	8.15	2.27	5.23	1.78	5.14	1.55	118.25	47.03	782.57	427.07	19.92	6.98
Women (20 to 70 years) n=75												
	Mean sw. (mm)	S(Ms)	**Trans (mm)**	S(Ts)	**Sagit (mm)**	S(Ss)	**Sw. Index**	S(Si)	**Sw. Area (mm^2)**	S(Sa)	**Sway vel. (mm/s)**	S(Sv)
Sway 1	5.78	1.64	3.34	1.05	3.99	1.38	159.81	27.19	315.55	170.03	10.35	3.16
Sway 2	6.17	2.01	3.59	1.16	4.23	1.62	153.85	34.68	432.67	285.14	13.97	5.27
Sway 3	7.27	2.41	4.40	1.70	4.81	1.85	135.81	45.48	456.75	252.11	11.37	3.18
Sway 4	7.80	2.50	4.59	1.47	5.32	1.91	125.55	46.14	670.32	465.05	16.79	5.26
Men and Women (20 to 70 years) n=150												
	Mean sw. (mm)	S(Ms)	**Trans (mm)**	S(Ts)	**Sagit (mm)**	S(Ss)	**Sw. Index**	S(Si)	**Sw. Area (mm^2)**	S(Sa)	**Sway vel. (mm/s)**	S(Sv)
Sway 1	5.99	1.83	3.39	0.99	4.19	1.64	156.14	33.00	341.87	198.17	11.29	3.60
Sway 2	6.42	1.93	3.91	1.40	4.23	1.41	150.37	35.63	469.42	284.20	15.09	5.59
Sway 3	7.36	2.24	4.48	1.63	4.86	1.75	132.69	44.89	468.87	255.44	12.11	3.67
Sway 4	7.97	2.39	4.91	1.65	5.23	1.74	121.90	46.57	726.45	448.52	18.35	6.36

Table 8: New performance values for Harmonic Index

Hand	Mean	SD	Minimum	Maximum
Right	2.1437	0.378	1.3883	2.8991
Left	2.0065	0.331	1.3445	2.6685