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Assistive technology to improve PC interaction for people with intention tremor

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Abstract—Many patients with upper limb intention tremor encounter difficulties in mouse-driven interaction with the personal computer (PC). An assistive technology system ("the Tremor Control System"), consisting of a motion-filtering software program that supports multiple interfaces, was developed and validated with 36 persons with Multiple Sclerosis in a multi-center trial. PC-tests, requiring basic functions such as cursor placement and click and drag function, were able to differentiate between patients and control subjects (ANOVA: $p<0.05$). A significant time improvement on the PC-tests was found when using an optimal alternative interface instead of the standard PC-mouse (paired t-tests: $p<0.01$ for Point & Click test, $p<0.05$ for Drag & Drop test and $p<0.1$ for Double Click test). A significant time improvement was found for the Double Click test (paired t-tests: $p<0.05$) when the motion-filtering program was implemented. The number of patients able to perform fully the PC-tests increased with the Tremor Control System. Patients with marked intention tremor seemed to profit especially from this assistive technology. These users reported that working with the Tremor Control System was less fatiguing and more comfortable compared to the use of the standard PC-mouse.

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INTRODUCTION

Multiple Sclerosis (MS) is the most frequent disabling neurological disease in young adults in North America and Western Europe, with an estimated prevalence between 30 and 120 per 100,000 inhabitants (1, 2). Intention tremor in the upper limb is encountered in approximately one-third of the MS population (2–4). Intention tremor is defined as an increase in tremor amplitude toward the termination of a visually guided, goal-directed movement (1,5–7). The tremor has a low frequency (3–6 Hz) and tends to worsen with increasing precision requirements (3,5,8–10). The term cerebellar tremor is often used synonymously with intention tremor and is commonly associated with disruptions of the cerebellum or its afferent or efferent pathways (3,5,11). Intention tremor is a largely underestimated cause of disability, probably because it is usually part of a wider clinical picture where strength often is preserved but movement control is affected (12). The functional impact of tremor may be overlooked easily in standard neurological examination. Nevertheless, even the mildest degree of intention tremor may disrupt a patient's

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handwriting, PC-interaction or independence in grooming and eating. There is, as yet, no satisfactory treatment for intention tremor (2–4).

Human-machine interaction is becoming essential for full participation in society because of the increased presence of computers in work and everyday life and their important role in communication and information gathering. Graphical user interfaces, such as Microsoft Windows and graphic packages, are standard in personal computers. The ability to successfully use a mouse or other cursor control device is crucial to enabling rehabilitation to gain functional independence for many persons with movements disorders (12–14). However, a considerable number of patients with upper limb intention tremor experience difficulties operating the standard PC-mouse. Therefore, one key objective of the "TREMOR" project was to develop assistive technology to improve mouse-driven screen functions during PC-interaction or, in the future, to control other computerized devices to assist activities of daily life. The aim of this study was to investigate the validity of the "Tremor Control System," which was developed especially for users with upper limb intention tremor.

METHODS

Description of the Tremor Control System

The "Tremor Control System" is an assistive technology system which has been developed by Scuola Superiore St-Anna (I) in collaboration with clinical centers. It consists of a motion-filtering program that supports multiple interfaces.

The *motion-filtering program* is a signal processing software program which allows different options for filtering the individual features of tremor during mouse-driven PC interaction. The voluntary movement characteristics are extracted, allowing the patient with intention tremor to interact more accurately with PC applications. The program only manipulates the cursor movements on the screen without physically affecting the movement of the interface, i.e., only the relationship between the mouse movement and cursor movement is altered.

The configurable parameters of the motion-filtering program and the design of the filter, respectively, are shown in **Figures 1 and 2**.

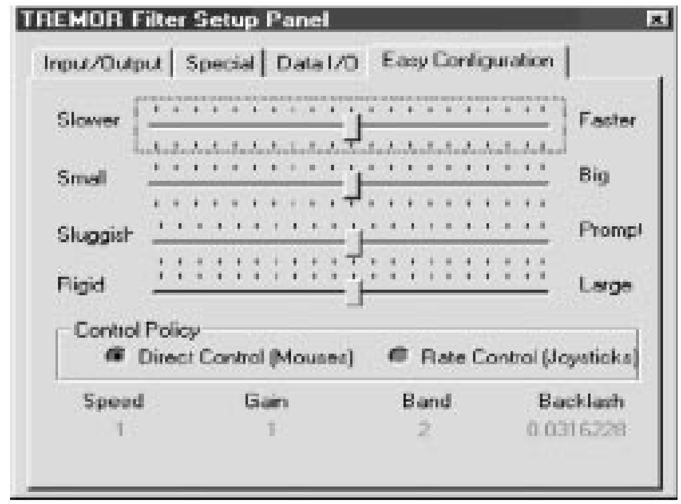

Figure 1.
Computer screen showing the configurable parameters in the motion-filtering program.

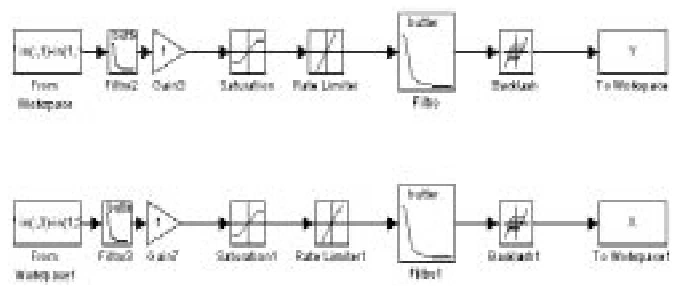

Figure 2.
Filter design.

- The *speed* parameter (slower-faster slider) regulates the maximum velocity that is allowed to the pointer for representation of the movement on the screen. Fast interface movements induced by tremor can thus be ignored for cursor representation while still allowing slower voluntary movements to be registered.
- The *gain* factor (small-big slider) regulates the geometric gain as it is applied on the input signal (i.e., interface movement) to compute the cursor position. Consequently, it influences the represented amplitude of tremor and the dimensions of the physically required operating workspace for the interface.
- The *band* (sluggish-prompt slider) consists of a II order Butterworth filter which defines the admissible frequency band for the system. The filter is able to reduce the frequency components of tremor between 2–6 Hertz. Using the lower setting, tremor frequency will be attenuated but other fast movements may also be slowed. Therefore, a sluggish configuration can only be

applied if the user accepts considerable slowing of their interaction with the PC.

- The *backlash* parameter (rigid-large slider) provides a control on the backlash block in the design of the filter. Each user input signal whose amplitude lies below this threshold is not considered within the movement representation of the cursor. Large backlash values cancel medium amplitude tremor without introducing any delay but may make the use of the interface more difficult. The backlash parameter should be a compromise between the effective amplitude of the tremor, the physically available workspace, and the required precision on the screen, as input values below the selected threshold will be ignored.

The features of intention tremor during mouse-driven PC-interaction may differ in individual patients. Therefore, the configurable filtering parameters allow the user (therapist and patient) to determine the best filtering options for individual optimum use.

The *interface support option* allows simultaneous input from the standard PC-mouse and alternative interfaces so that two individuals, one disabled and one able-bodied can share PC use. The alternative interfaces used in this study are presented in **Figure 3**. These included a game joystick, a force-control joystick, a trackball (Rollerball), a cordless mouse (unilateral or bilateral use) and a helmet carrying an infrared movement sensor.

The Tremor Control System is an easy access interface for computer systems based on the Windows 95/98 operating system. The system allows normal interaction with common multimedia programs available for personal computers such as Internet Browser, graphic packages, text editors or games.

Figure 3.
Interface support option: *from left to right*: game joystick, force-control joystick, trackball, cordless mice (bilateral and unilateral shaped), standard mouse, helmet.

Patient Selection Criteria and Assessment

MS patients with upper limb intention tremor were selected from three European Rehabilitation Centers (National Multiple Sclerosis Centre, Melsbroek (Belgium), Masku Neurological Rehabilitation Center (Finland) and the MS Unit of Bristol General Hospital (United Kingdom)). All patients gave their informed consent to participate to the trials. Patients with paresis in the upper limb used in the trials, or who manifested visual or mental impairment or an exacerbation of their MS over the month before testing, were excluded. Paresis in the non-tested upper limb was acceptable.

The *clinical assessment* to document level of intention tremor consisted of the Finger-to-Nose test, scored according to Fahn's Tremor Rating Scale (15), and the Nine Hole Peg test (16). Fahn's Tremor Rating Scale is a five-point rating scale where zero is no tremor and four is severe tremor. The Nine Hole Peg test is a functional performance test to measure hand dexterity and is commonly used in MS (17, 18). The number of pegs (maximally nine) placed within 50 s is counted.

PC-tests were constructed to measure objectively the mouse-driven PC-interaction. The tests required the basic functions used in controlling an interface, i.e., cursor positioning, single and double click-and-drag functions, which imply accuracy and stability in controlling the cursor. Time needed to complete each test was measured and the presence or absence of compensation techniques was observed. The three tests were as follows:

1. Point & Click test. The subject had to click on three targets on the screen in a predefined order.
2. Drag & Drop test. Five objects representing files had to be dragged from one directory box into another. The destination box was smaller than the pick-up box, requiring accuracy in placing the transferred files. The number of inaccurate trails (i.e., file placed outside the destination box) was additionally counted.
3. Double Click test. The patient was asked to open one file by making a double click. The number of "click attempts" was additionally recorded.

Patient satisfaction with the alternative interface and motion-filtering program (confer 'test procedure') was addressed with four questions: 1)“Does the interface make it easy to control the cursor?”; 2)“Can you easily push on the buttons?”; 3)“Does using the system fatigue you?”; and 4)“Is the system comfortable to use?” Outcome measure was the Visual Analogue Scale ranging from “not at all” (zero) to “fully” (ten).

Test Procedure and Data Analysis

The user decided which hand was to be used for operating the interfaces. The performance of each patient during mouse-driven PC-interaction was clinically observed. The potential benefit of the Tremor Control System was explored during “trial and error” sessions. Several interfaces were tested and an optimal one chosen for each subject. Configurations of parameters in the motion-filtering program were tried out and adapted to the individual needs of the patient.

Finally, the patient was evaluated with the PC-tests in three different stages during a separate evaluation session. All PC-tests were first performed with the “standard mouse” (stage 1), secondly with the “optimal interface support” (stage 2) and finally with the “optimal interface support AND optimal configuration of parameters in the motion-filtering program” (stage 3). Control subjects performed the PC-tests using the standard PC-mouse.

Means and standard deviations (SD) were calculated for all outcome measures. Analysis of variance (ANOVA) was used to investigate whether differences of means were statistically significant. Patients who were unable to perform fully a PC-test in stage 1 were excluded from the data analysis of time-related outcome measures due to lack of an exact numerical value.

RESULTS

Sample and Clinical Assessment

Thirty-six (17 male, 19 female) MS patients with upper limb intention tremor participated to this multi-center trial. Mean age was 42.9 y (SD=9.8). The results of the clinical assessment are presented in **Table 1**. One third of the sample, respectively, showed slight, moderate, and marked or severe intention tremor during the Finger-to-Nose test rated with Fahn’s Tremor Rating Scale. Eighteen subjects could place 7 to 9 pegs within 50 s during the Nine Hole Peg test, 9 were able to place 4 to 6 pegs and a further 9 subjects placed 0 to 3 pegs.

PC-Performance Using Standard PC-Mouse

Results of patient and control groups (16 able-bodied persons, mean age 38.3 y) with the PC-tests, using the standard PC-mouse, are presented in **Table 2**. Patients who were unable to perform fully the test were excluded from statistical data analysis, as no numerical outcomes were available. These included 3 patients for the Point & Click test, 6 for the Drag & Drop test and 14 patients for the Double Click test.

Mean time to complete the tests for patient and control group, respectively, was 18.1 s and 4.8 s on the Point & Click test, 57.8 s and 11.4 s on the Drag & Drop test and 9.8 s and 1.6 s on the Double Click test. The difference between the mean performance of patient and control groups was found statistically significant for all PC-tests (ANOVA, t-test; $p<0.05$).

Choice of Optimal Interface and Motion-filtering Program

Three patients (8.3 percent) chose the standard mouse as optimal interface, 14 (38.8 percent) the unilateral and 5 (13.8 percent) the bilateral shaped cordless mouse. Eleven (30.5 percent) chose the trackball, 2 (5.5 percent) the forced-joystick and 1 (2.7 percent) the helmet. Nobody chose the game joystick. The acceptance by subject was addressed with questions concerning the ease of control of the cursor and push on the buttons. Mean outcome was 3.8 and 5.3, respectively, when using the standard mouse, and 6.1 and 7.2,respectively, when using the optimal interface. The difference of means between

Table 1.
Clinical assessment of intention tremor

Fahn’s Tremor Rating Scale		**Nine Hole Peg Test**	
None	0%	7-9 pegs	50% (n=18)
Slight	34.4%(n=12)	4-6 pegs	25%(n=9)
Moderate	34.4%(n=12	0-3 pegs	25%(n=9)
Marked	22.9%(n=8)		
Severe	11.4%(n=4)		

Table 2.
Results of patient and control group on PC-assessment using the standard PC-mouse. Patients who were unable to fully perform the test were excluded for data analysis

	Patients			Controls (n=16)
PC-Tests	Mean time (SD)	Min/max	Patients able to fully perform the test	Mean time (SD)
Point & Click test	18.1 s (10.8)	5.1–104	33	4.8 s (1.6)
Drag & Drop test	57.8 s (43.4)	17.6–190	30	11.4 s (3.5)
Double Click test	9.8 s (10.5)	1.5–71	22	1.6 s(0.96)

two conditions was significant for both questions (p<0.01) (paired t-test).

The configuration of parameters differed between individual patients. No significant correlation between the defined configurations and either clinical or PC assessment was found.

Intervention with the Tremor Control System

Mean time-performances on the PC-tests during all evaluation stages are shown in **Figure 4**. Patients who could not fully perform the test using the standard mouse were excluded for statistical data analysis in all stages because of the lack of an exact numerical value with which to refer. Mean time performance (SD) in stages 1, 2 and 3, respectively, was: 18.1 s (10.8), 13.5 s (6.4) and 18.1 s (13.2) on the Point & Click test; 59.4 s (43.4), 44.7 s (24) and 57.9 s (39.1) on the Drag & Drop test; and, 9.8 s (10.4), 6.0 s (4.7) and 5.5 s (3.3) on the Double Click test. A statistically significant improvement in time was found for all PC-tests at stage 2 (paired t-test: p<0.01 for Point & Click, p<0.05 for Drag & Drop and p<0.1 for Double Click test) and for the Double Click test in stage 3 (p<0.05) compared to stage 1.

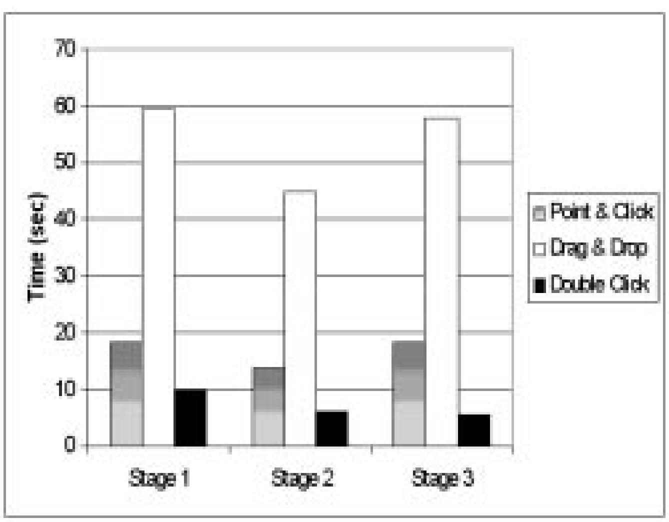

Figure 4.
Time performance on the PC-tests for all evaluation stages.

Descriptive data concerning the PC-assessment during all evaluation stages are presented in **Table 3**. The number of patients able to perform fully the PC-tests was higher in stages 2 and 3 compared to stage 1. The number of patients using compensation techniques to decrease intention tremor during PC-interaction decreased in stages 2 and 3 compared to stage 1. Commonly observed techniques were: stabilization of the conducting arm with the other hand, fixation of the upper extremity against the trunk, or support of the lower-arm on the table or the armrest of the chair. The number of inaccurate trials during the Drag & Drop test and the number of click attempts during the Double Click test was lower in stage 2 compared to stage 1. An additional decrease of the number of click attempts was observed in stage 3 for the Double Click test.

The satisfaction of patients in using the system was assessed by questions concerning fatigue and comfort and was scored on a visual analogue scale. Mean outcomes for stages 1, 2 and 3, respectively, were 4.5, 2.7 and 3.6 for fatigue, and 4.5, 7.1 and 5.5 for comfort. The mean difference between stages 1 and 2 was significant for both questions (paired t-test, p<0.01), as opposed to a lack of significance of the differences between stages 1 and 3.

Further Data Analysis on Subgroups

Subgroups were assigned based on the clinical performance on the Nine Hole Peg test. Mean time performance of each subgroup on the PC-tests is shown in **Figure 5** for all evaluation stages. Due to the small size of the subgroups, differences between means have not been statistically analyzed. The patient group with the worst clinical performance on the Nine Hole Peg test

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Table 3.
Number of patients able to fully perform a PC-test, and with the use of a compensation technique, total number of inaccurate trails in Drag & Drop test and total number of attempts for Double Click test

	Stage1	Stage 2	Stage 3
Number of patients able to fully perform a PC-test:			
Point & Click test	33	36	36
Drag & Drop test	30	32	33
Double Click test	22	29	31
Number of patients using a compensation technique	17	10	7
Drag & Drop test: Total number of inaccurate trails	95	30	40
Double Click test: Total number of click attempts	162	100	87

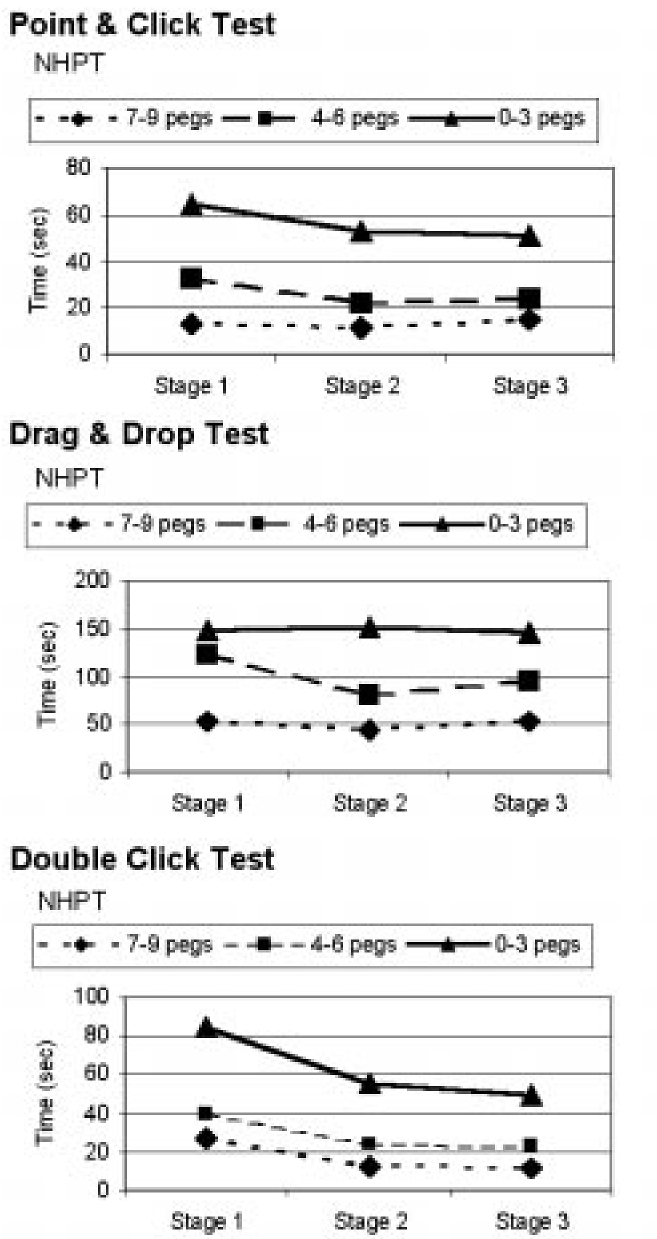

Figure 5.
Time performance of subgroups on the PC-tests for all evaluation stages.

(0-3 pegs placed within 50 s) showed the greatest benefit from using the motion-filtering program in stage 3, for both the Point & Click and Double Click tests. The subgroup with the best clinical performance did not appear to profit from the implementation of the motion-filtering program although choice of an optimal interface (stage 2) did show some benefit.

The degree of satisfaction in using the Tremor Control System is shown in **Figure 6**. The subgroup with worst clinical performance on the Nine Hole Peg test reported the lowest score concerning fatigue and the highest score concerning comfort, with the motion-filtering program enabled in stage 3. The subgroup with the best clinical scores preferred the implementation of the optimal interface only.

DISCUSSION

Operating the cursor during PC-interaction is a challenging activity for patients with upper limb intention tremor. The aim of assistive technology systems is to improve functional capabilities in individuals with disabilities (19). The objective of this study was to test whether the Tremor Control System was able to improve mouse-driven PC-interaction in persons with upper limb intention tremor (19).

The evaluation of the capacity of a person to interact properly with the personal computer, using a graphical user interface, is poorly documented in the literature (20). There is a clinical need for an objective assessment of PC-interaction which is highly functional, in contrast to tracking tasks only (12, 13, 21). The PC-tests used in this study were able to differentiate between non-tremor subjects and patients with intention tremor (20). The difficulties of patients in using accurately the standard PC-mouse was reflected in their longer performance times, which were even underestimated when the data of

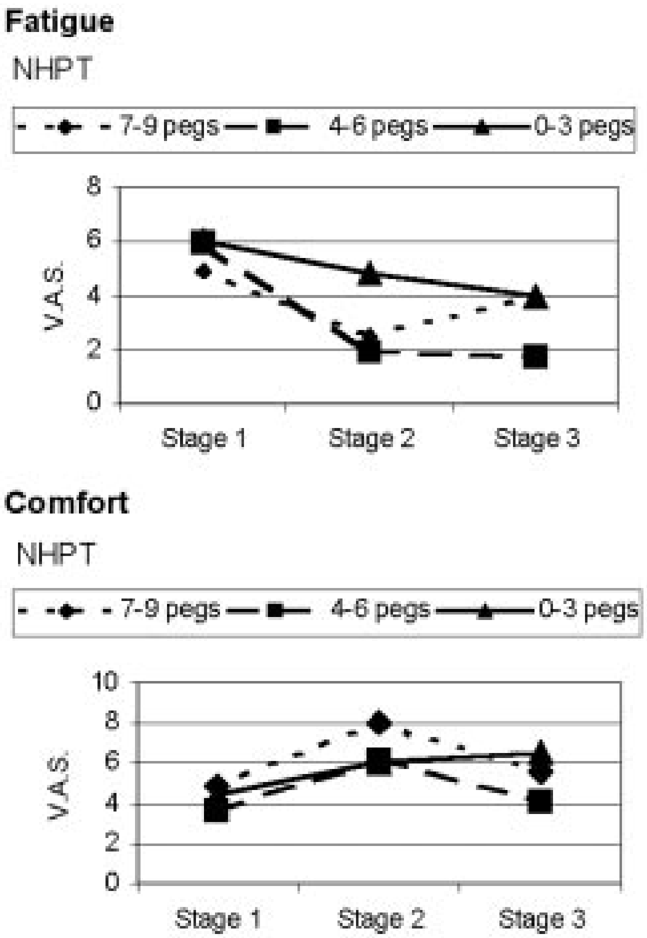

Figure 6.
Degree of satisfaction.

patients who were unable to fully perform the PC-test were excluded for statistical analysis. Intention tremor is suggested to be dependent on visual information since it has been found to aggravate during visually guided movements (22–24). The use of visual feedback from the cursor representation on the screen is essential during mouse-driven PC-interaction. Similar to observations of the elderly, making a double click with the standard mouse was found to be a complex task. In our sample, this observation was expected since patients with cerebellar deficits have difficulties in making fast, repetitive movements (20,25).

The selection of an individual, optimal interface improved speed of execution on all PC-tests and decreased the number of inaccurate actions during both click and drag tasks, implying that operation of the cursor was performed more efficiently. The acceptance by the subjects of an alternative interface for the standard mouse was high; its use was less fatiguing and more comfortable. Controlling the cursor and pushing the buttons of the interface was easier, probably because of features such as appropriate position of the buttons, type of conducting mechanism, and size and shape of the chosen interface.

The implementation of the motion-filtering program improved time performance on most PC tests, but statistical significance was found for the Double Click test only. Further data analyses on subgroups were performed to investigate whether one patient group gained more benefit than another from the motion-filtering program. Ranking the subjects by clinical performance on the Nine Hole Peg test showed that the improvement of time performance seemed to cluster at the lower end of the clinical performance scale. Since more severe tremor is more disabling, any improvement achieved probably implies better functional ability (12). Patients with the worst clinical performance showed the best time performance on most PC-tests when the motion-filtering program was implemented, in contrary to patient groups with better initial clinical performance. Simultaneously, the most severely affected patients reported the highest degree of satisfaction when using the motion-filtering program while patients with slight or moderate conditions experienced no or little benefit. In fact, many found that implementing the software slowed their performance without substantially improving accuracy of cursor control.

Time measurement might not fully reflect the quality of PC-interaction; therefore, other parameters were taken into account. The number of persons who were able to perform fully the PC-tests with the Tremor Control System increased compared to the use of the standard PC-mouse. It is important to note this, since these patients were not included for statistical data analysis although a time improvement was observed.

The quality of PC-interaction improved as operation of the cursor was performed more efficiently and subjects were more relaxed, with less need for additional stabilization of the upper limb.

The results of this study showed that the movement filtering parameters could be configured to enable improved PC-interaction especially for those with marked intention tremor. The clinical aspects of intention tremor (overshoot and tremor velocity, amplitude and frequency) were highly variable between patients, and individuals were found to benefit from various combinations of control set-ups. However, no single configuration of parameters was beneficial for all patients. This fact highlights the importance of the flexibility available in the motion-filtering program, allowing a range of configurations to be selected according to individual tremor features, which may change over time. An important advance in the motion-filtering program is the simplification of this configuration phase, which enhances the usability of the system (12,19). Following the initial setting up of parameters, based on clinical assessment, the user is able to alter the parameters using the on-screen software options. Future developments focus on further simplification of the system by employing an automatic configuration procedure, using a mathematical index calculated from the input signal (26).

An important feature of the motion-filtering system is the potential to share the personal computer with other users, via the standard mouse input. Playing of games and other family, social, or work-related PC activities can be shared, enhancing the ability of the patient to integrate, and having important psychological benefits (27). This study showed the validity of the Tremor Control System for persons with marked intention tremor in the upper limb. Preliminary results of ongoing trials with children with cerebellar ataxia in the upper limb indicate a similar beneficial effect. It is hoped that the Tremor Control System will be available shortly, at modest cost.

CONCLUSIONS

This study demonstrated how persons even with severe level of disabling intention tremor are capable to improve their PC-performance with appropriate technical solutions. The Tremor Control System extended the number of patients with upper limb intention tremor able to interact with the PC and enhanced the quality of operating the cursor. PC interaction was performed faster and more efficiently. Especially patients with marked intention tremor experienced the system as less fatiguing and more comfortable. Health care professionals are challenged to integrate these findings in clinical practice to enhance the functional independence of their patients in man-machine interaction.

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