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Brain Computer Interface Cursor Measures for Motion-impaired and Able-bodied Users

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Abstract

This paper presents the results of experimental studies that aim to measure the effectiveness of a Brain Computer Interface (BCI) against a mouse on “point and click” tasks performed by able-bodied and upper-limp motion-impaired users. Our methodology is based on the ISO 9241-9 guidelines. We examine how Fitts’ law fits the tested input devices, and we use gross and detailed trajectory measures in order to quantify cursor movement and evaluate performance. We conclude that Fitts’ law can only describe able-bodied users’ performance when selecting targets with the mouse. On the other hand, the performance of both user groups with the BCI, and of motion-impaired users with the mouse does not conform to Fitts’ law. Tables and charts of results are given, showing that the BCI cannot currently compete with the mouse in terms of usability, but can be used as an alternative for motion actuated devices when no other solution is possible.

1 Introduction

There are individuals who, because of the severity of their physical limitations, have been unable to access a computer through either direct selection or alternative interaction methods, such as combinations of scanning techniques and switches. On the other hand, there are circumstances in which able-bodied users cannot use their hands during an HCI interaction. For those cases the emerging Brain Computer Interface (BCI) technology could be a candidate alternative (Barreto, Scargle & Adjouadi, 2000), (Bayliss & Auernheimer, 2001), (Ming, Dingfeng, Xiaorong & Shangkai, 2001).

We conducted a series of methodological experimental studies on the performance of able-bodied (AB) and motion-impaired (MI) users, using a Logitech® Cordless Wheel Mouse™ and a Brain Actuated Technologies® Cyberlink™ Brainfingers™ BCI System. The subjects were four able-bodied and four disabled users. Two different experiments were set up in order to examine Fitts’ law application in one-direction point and click tasks (MacKenzie, Sellen & Buxton, 1991), and to extract detailed trajectory and target selection measures in multidirectional tasks (Oh & Stuerzlinger, 2002). The design of the tests was based on the guidelines provided by ISO 9241-9: *Ergonomic requirements for office work with visual display terminals (VDTs)-Part 9: Requirements for non-keyboard input devices* (ISO/TC 159 & CMC, 2000), (MacKenzie, 2001).

Proprietary software was developed using Microsoft® Visual Basic to provide the applicable User Interface (UI), and to acquire, store and analyze cursor movement data. Microsoft® Excel was also used for data processing. In all "point and click" experiments users were instructed not to stop on erroneous clicks and an audio feedback was given in that case (trial was not interrupted). Visual and audio feedback was also given for successful clicks. Each task was explained and demonstrated to the participants and a warm up block of trials was given. A 100 Hz sampling rate was used for trajectory and click data acquisition (x, y coordinates, millisecond precision time).

2 Experiments

In the one-direction test (first test), two rectangular targets of the same width W, separated by distance D appear on the screen. The task is to point and click each rectangle 10 times for every block of trials performing back and forth movements between the two targets. Each trial block commences with the cursor locked on the left rectangle and the user must click to unlock the cursor and let the data acquisition begin. The initial click action is not taken into consideration for the measures. The next rectangle that must be clicked each time is highlighted. On every successful selection the cursor moves to the center of the selected target so that the user can continue uninterrupted and D will be the same at all times. Nine test blocks for different Fitts' difficulty indexes (i.e. 3 D and 3 W combinations) varying from 1.24 to 4 bits are run, yielding a total of 180 trials for each user and each device (20 trials per block x [3 W x 3 D] blocks). Applied distances were: 150, 300 and 450 pixels and widths: 30, 70 and 110 pixels. We used Equation 1 to examine Fitts' law application on our data and to calculate difficulty indexes (ID); this variation of the equation has been proven the most appropriate for our purpose and most widely used (Accot & Zhai, 1997), (MacKenzie, 1991). According to Fitts, Movement Time (MT) must be linearly related to ID.

Equation 1: $MT = a + b \cdot ID$, where $ID = \log_2\left(\frac{D}{W} + 1\right)$

In the multi-directional test (second test), 16 square targets are arranged in an equidistance circular layout. The task begins with a click on the topmost target; then the subject must move the cursor directly to the opposite target and click on it, and so on clockwise round. Every time a target is selected, the cursor moves automatically on its centre and the next target is highlighted. Each trial block is completed when all targets have been selected (17 trials as the topmost target is the end) and 9 blocks are run for the combinations of 3 different radii (D/2: 160, 230 and 300 pixels) and target widths (W: 30, 40 and 50 pixels) for each user and each device. Derived Indexes of Difficulty varied form 2.89, to 4.39 bits, but only cursor measures taken with ID=3.64 bits (corresponding to D= 460 and W=40) will be presented in this paper.

3 Results

All our motion-impaired subjects were quadriplegic with severe disabilities in their upper limbs and two of them could not manage to finish the tests neither with the mouse nor with the BCI due to various reasons like lack of interest, mental problems, inability to use motor skills and spasm (Langdon, Keates, Clarkson & Robinson, 2001). Those users' data were excluded. Four AB and two IM users completed all the tests successfully with both devices.

The operation of the BCI device is based on EEG, EMG and OMG signals acquired by three electrodes mounted on a headband (Penny & Roberts, 1999). Nevertheless, mainly EMG and OMG signals were used to control the cursor because we could not manipulate EEG signals (after a two-months trying period). Facial muscles and eye movements controlled the mouse cursor in the following manner: clenching the teeth resulted in click; rapid eye movement or blink moved the cursor to the left; unwavering stare moved the cursor to the right; putting tension on the forehead moved the cursor upwards and relaxing forehead muscles move the cursor downwards.

At the end of the experiment, subjects were interviewed and asked to complete a questionnaire so as to evaluate the perceived performance from the participants' perspective (comfort). MI users were tired from both devices while AB users were only tired from using the BCI. No one thought that the BCI was an easy to use device and everybody said that its use was not so pleasant and its accuracy and speed quite low.

Our first goal was to examine how Fitts' Law applies to mouse and BCI cursor movements and compare our measurements and results between subjects, devices, task primitives and data found in the literature (Gillan, Holden, Adam, Rudisill & Magee, 1990), (Oel, Schmidt & Schmidt, 2001), (Douglas, Kirkpatrick & MacKenzie, 1999).

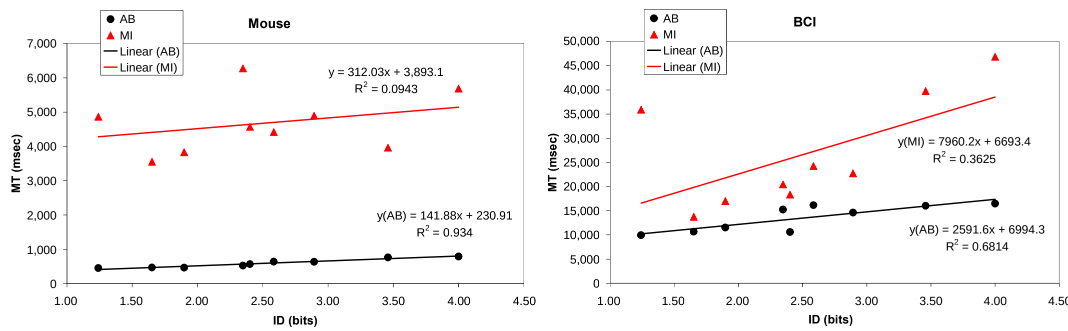

Figure 1: Scatter-plot graph of the Movement Time (MT) – Index of Difficulty (ID) relationship

In Figure 1 we summarize results from the one-direction tapping test, and Fitts' law application is illustrated. In the first graph (mouse) the linearity between MT and ID is quite obvious for able-bodied (AB) users with the fitting line giving R^2=0.934. On the other hand, the estimated values of the trend line doesn't correspond so closely to the actual data for motion-impaired (MI) users, giving R^2=0.094, which is very low. Fitts' law cannot describe the rough or spastic movements of MI users' hands. As far as the BCI is concerned, the second graph of Figure 1 shows that Fitts' law doesn't fit neither of the two user groups giving R^2=0.681 for AB, and R^2=0.362 for MI users.

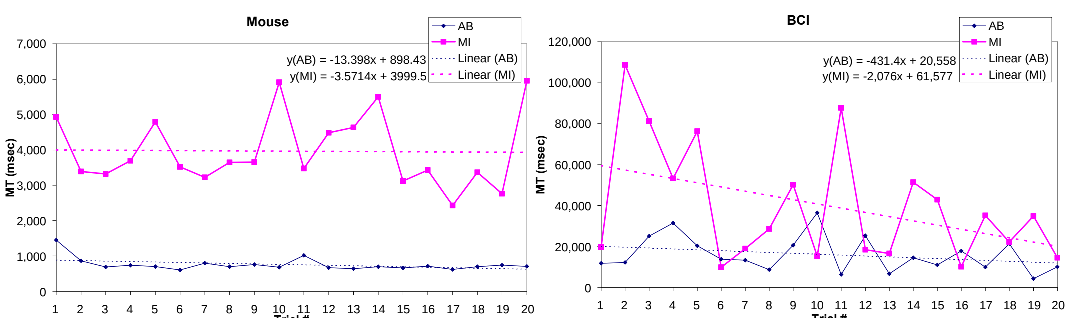

Figure 2: Average Movement Time (MT) by User Group (AB-MI) by Trial number

Figure 2 illustrates the learning effect by user group by trial (1-D test). It must be noted here that biofeedback was an important factor in the BCI learning process. Furthermore three of four AB users were previously trained in BCI use, while MI users had their first contact with the device just before the experiments and carried out a learning and warm up procedure (2 hours). All users had experience in using mice or trackballs. In other studies these graphs are presented having block number on x-axis. Our data are presented as Movement Times averaged through blocks of different index of difficulty, in relation with trial number (each block consists of 20 trials), showing the learning effect within an "average" block. We see a considerable performance improvement for both user groups and devices, which is much larger for the BCI than the mouse and quite impressive in the case of MI users using the BCI, showing their big potential to learn to use the device much better and surpass AB users' performance (something that cannot happen for the mouse). Fitting line slopes were: (AB,mouse)=13.4, (MI,mouse)=3.6, (AB,BCI)=431.4, (MI,BCI)=2,076.

Our second objective was to quantify cursor movement effectiveness and have comparable results with other studies. We used a number of cursor control measures which can be grouped in two sets: Gross measures for performance evaluation: *Movement Time (MT), Effective Target Width (W_e), Throughput ($TP=ID_e/MT$) and Missed Clicks (MCL)* and detailed trajectory measures: *Target Re-entry (TRE), Task Axis Crossing (TAC), Movement Direction Change (MDC), Movement Variability (MV), Movement Error (ME) and Movement Offset (MO)* (MacKenzie, Kauppinen & Silfverberg, 2001), (Keates, Hwang, Langdon, Clarkson & Robinson, 2002).

The results of the multi-directional tasks are summarized in Table 2. The data for the two user groups and mouse use, are comparable to numbers from other studies (see Keates et al, 2002), and show clearly the difficulties that MI users have. For the BCI the results seem rather disappointing, but they were anticipated. With further user training and experience on the device we expect these numbers to improve in future studies.

Table 1: Means and standard deviations of the measures for the two user groups for each device

MOUSE		
Cursor Measures	AB users Mean *(SD)*	MI users Mean *(SD)*
MCL	0.03 *(0.06)*	0,17 *(0,25)*
TRE	0.09 *(0.11)*	0.09 *(0.12)*
TAC	1.47 *(0.21)*	1.85 *(0.21)*
MDC	19.47 *(2.54)*	65.47 *(12.72)*
ME	14.86 *(2.70)*	24.27 *(11.83)*
MO	-0.98 *(4.68)*	-16.82 *(15.41)*
MV	21.58 *(4.23)*	44.08 *(17.31)*
MT	0.762 *(0.045)*	4.18 *(0.77)*
W_e	22.74 *(3.42)*	19.75 *(1.45)*
TP	5.81 *(0.57)*	1.12 *(0.18)*

BCI		
Cursor Measures	AB users Mean *(SD)*	MI users Mean *(SD)*
MCL	0.75 *(0,79)*	3.05 *(2.25)*
TRE	0.39 *(0.15)*	1.4 *(0.66)*
TAC	5.87 *(0.41)*	14.63 *(10.28)*
MDC	422.38 *(44.77)*	1,161.44 *(995.89)*
ME	130.55 *(16.87)*	201.82 *(112.36)*
O	58.82 *(8.14)*	122.85 *(73.31)*
MV	167.15 *(22.32)*	263.27 *(150.08)*
MT	25.564 *(0.701)*	104.69 *(106.65)*
W_e	23.16 *(1.98)*	30.53 *(3.19)*
TP	0.182 *(0.007)*	0.081 *(0.084)*

4 Conclusions

For BCI devices, there are no data in the literature to compare and the results we acquired indicated that BCI does not seem to be competitive to hand actuated devices, as this is a distant prospect. On the other hand, the results show that motion impaired users do have an alternative solution for interacting with a computer, even if they don't have any remaining ability of moving or controlling any part of their body (except face muscles). Furthermore, we were able to establish conclusions about how increasing user familiarization and training affect the measures, which is especially interesting in the BCI case.

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