

MouseField: Evaluating a Cursor Pointing Facilitation Technique for Cerebral Palsy

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This paper evaluates the performance of users with cerebral palsy (CP) using an inertial human-computer interface (HCI) based on head movements and a novel facilitation algorithm for users with mild to severe motor disorders that we named MouseField. Seventeen users from 3 centers specialized in CP participated in a series of tests that analyzed 10 measures of rapidity and accuracy in reaching tasks using an inertial interface with and without the MouseField algorithm. Cluster analysis was used to classify the users in three categories, C₁-C₃ ordered by rapidity. MouseField improved rapidity in C₂ and C₃ and accuracy in C₃. Although a loss of accuracy was detected for the least impaired (C₁, MACS IV-V), MouseField proved to improve task performance of users with severe motor disorders (MACS V), with decrements of 33.3% and 65.5% in the movement times. Our experiments show that MouseField can be used to complement the inertial interface, ENLAZA, in order to facilitate navigation and minimize targeting errors, respectively, for users with severe motor impairments that are not able to use traditional mice or joysticks.

Keywords: human-computer interaction; cerebral palsy; inertial sensor; head movement; gravity wells; pointing facilitation; clustering

1. INTRODUCTION

Cerebral palsy (CP) is one of the most severe disabilities in childhood and makes heavy demands on health, educational, and social services as well as on families and children themselves. Bax et al. (2005) defined CP as ‘a disorder of movement and posture due to a defect or lesion of the immature brain’. Those disorders of posture and movement which are (1) of short duration, (2) due to progressive disease or (3) due solely to mental deficiency are usually excluded from CP. The prevalence of CP is internationally 1.5-2.8 cases per 1000 births. According to Winter et al. (2002), in the United States 0.5 million infants are affected by CP. Johnson et al. (2002) claimed that those figures are slightly higher in Europe; the overall rate for the period from 1980 to 1990 was

2.08 per 1000 live births and there are nearly 17 million people with CP worldwide of all ethnicities and social status. The work ‘Surveillance of cerebral palsy in Europe: a collaboration of cerebral palsy surveys and registers’ presented a consensus that was reached on a definition of CP, description and classification in terms of nosology, topography and function (severity). Cans (2007) divides the CP, according to a nosological classification, into three types: spastic, ataxic and dyskinetic. Spastic CP is the most common form (70-80% of the individuals with CP are affected by spasticity) and is characterized by at least two of these signs: abnormal pattern of posture and/or movement, increased tone and pathological reflexes. It may be either bilateral or unilateral. Ataxic CP (6%) is characterized by both abnormal pattern of posture and/or movement and loss of orderly muscular coordination;

movements are performed with abnormal force, rhythm and accuracy. Dyskinetic CP (6%) is dominated by both abnormal pattern of posture and or movement; and involuntary, uncontrolled, recurring, occasionally stereotyped movements (Cans (2007)).

Severe motor disorders in combination with sensory and cognitive alterations result in great difficulties for these people to communicate and interact with their environment. Consequently, alternative channels to control devices such as tablets, PCs and others are needed in order to overcome some of these limitations and promote neural plasticity, specially during childhood. These solutions enable pointing (Tuisku et al. (2014)), dragging (Cockburn et al. (2012)), scanning (Biswas and Langdon (2013)) or scrolling (Zhao et al. (2014)).

Unfortunately, few of them had undergone systematic evaluation for the specific needs of CP. As Almanji et al. (2014) argued, the use of assistive technology for computer access encounters barriers that lead to the use of typical mice, track balls or touch screens for practical reasons. New metrics to describe the motor behavior of users with diplegia are needed in order to develop new techniques that could facilitate pointing tasks, which is vital since 65% of youths with CP that were MACS IV and V could not use standard mice nor keyboards (Davies et al. (2010)). The act of pointing to graphical elements such as icons or buttons is the most fundamental elemental tasks in HCI (Balakrishnan (2004)). Any pointing task can be described as a two-phase movement:

- **Ballistic phase**, in which the user tries to get close to the target with fast, gross movements.
- **Homing phase**, in which the user completes one or more precise submovements to reach the target.

People with severe motor disorders usually deviate from this pointing model. Hurst et al. (2008) enumerated the problems that users with mobility and manipulation limitations encounter when they perform a reaching and clicking task. Those problems ranged from targeting errors (overshooting caused by difficulties moving mouse to a target or difficulties staying on a target) to navigation (difficulty moving mouse small or large distances or keeping mouse motion steady) or other problems related to clicking (pressing incorrect button and accidental or repeated click). Figure 1 represents how some of these problems affect the cursor trajectory.

In this study, we introduce MouseField, a pointing facilitation technique specially designed for users with poor fine motor skills. We hypothesized that people with CP are able to complete the ballistic phase easily and place the cursor in the surroundings of a certain target because they have developed relatively good gross motor control. Unfortunately, they lack good fine motor control, hence their inability to stop stay on the target

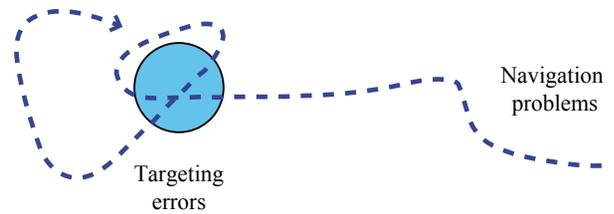


Figure 1. Typical cursor trajectory of users with CP with poorly developed fine motor control during a reaching and selecting task.

during the homing phase. Our study aimed to answer two questions:

- Is MouseField a valid pointing facilitation technique for people with CP and severe manipulation limitations?
- Which levels of functional score (measured by MACS or GMFCS) are more benefited from the use of MouseField?

In our experiments, we tried to answer those questions by analyzing cursor trajectories and other parameters that quantify rapidity and accuracy during pointing tasks. We tested for differences between two kinds of interaction: a head mouse named ENLAZA with and without MouseField. We expected to be able to confirm improvements in those users with worst motor skills when they use the MouseField algorithm. We also counted on measuring differences in the effects that this algorithm has in users with different levels of motor disorder according to functional scores.

1.1. Related Work

The simplest pointing facilitation algorithms rely on knowing the location and size of the targets on the screen (*target-aware*) while more complex solutions try to model user behavior and predict click intention (*target-agnostic*). Target-aware pointing facilitation is based on controlled modifications of the ballistic or homing phases during pointing tasks. Some of them try to “beat” Fitts’ law (Fitts (1992)) by changing two parameters in pointing tasks performance: target width and amplitude of the movement. Examples of this approach are the area cursor (Worden et al. (1997)), expandable buttons (McGuffin and Balakrishnan (2002) and Zhai et al. (2003)), object pointers that skip empty spaces (Guiard et al. (2004)), or the bubble cursors (Grossman et al. (2005)). Others, such as sticky icons (Worden et al. (1997) and Ahlström et al. (2006)), semantic pointing (Blanch et al. (2004)), gravity wells (Keates et al. (2000) and Hwang et al. (2003)) or

force fields (Ahlström et al. (2006)) produce local changes in the cursor-device (CD) gain. While the use of *objects pointing* (OP) to skip pointing cannot be modeled by Fitts’ law, increasing the size of either the cursor or the target reduces the movement times predicted by Fitts’ law. Even though all these solutions granted reductions in movement times in “cleared” screens with limited number of elements, there are some limitations when the amount of icons or buttons rises. The presence of *distractors*, i.e. elements in the trajectory between the cursor origin and the target, is known to be problematic as it impedes the performance of sticky icons, gravity wells or force fields. Performance is specially precarious when there are elements on the screen that are too close to each other. Area cursor could cover two or more elements, expandable buttons could produce occlusions and gravity wells could easily pull the cursor into a distractor.

While all these target-aware solutions proved to be useful in experimental conditions, the fact that they require precise knowledge of the the elements on the screen limits their performance in real-world applications. Target-agnostic approaches analyze cursor trajectories in order to predict click intention or difficulties to stay on a target. Algorithms as the *Angle Mouse* (Wobbrock et al. (2009)), *PointAssist* (Hourcade et al. (2010)) or *Dirty Desktops* (Hurst et al. (2007)) are based on analyzing angular deviation, detecting abnormal amounts of submovements and creating a click and drag database, respectively. While the *AngleMouse* and *PointAssist* modify CD gain in order to enhance precision during the homing phase, *Dirty Desktops* uses its database in order to feed an algorithm of force fields.

The development of user behavior models is critical, specially when their are developed for motor impaired users. Olds et al. (2008) and Rodriguez et al. (2010) modeled the interaction of athetoid people and Biswas and Langdon (2013) worked with CP and Spinabifida. Unfortunately, the complexity of developing models for specific profiles of motor disorder is a burden for the development of customizable facilitation algorithms.

1.2. The ENLAZA interface

Raya et al. (2012) proposed the ENLAZA interface, an adapted head mouse for users with severe motor disorders (specially CP) that cannot use traditional solutions such as mice, joysticks or trackballs to access the computer. ENLAZA allows users to control the cursor of the computer with movements of their heads and consists of a headset with a spectacle frame and a wireless inertial measurement unit, WIMU (Werium Assistive Solutions S.L., Spain) as depicted in Figure 5. The mouse pointer is controlled with an *absolute control*, meaning that there is a unique mapping between head orientation and location

of the pointer. During the calibration, a therapist adjusts the CD gain and detects the orientation of the head that corresponds to the *home position*. From that home position, the user will be able to reach all the pixels in the screen by head movements in two axes.

2. MOUSEFIELD

We developed MouseField as a pointing facilitation algorithm that focuses in targeting errors rather than navigation problems. It is intended for users with CP and other motor disorders that are able to locate the cursor in any screen location using ENLAZA but have difficulties staying on it or hovering over a small area, thus cannot use the *dwell click* . The development of the MouseField’s algorithm was inspired by some of the target-aware techniques described in Section 1.1, specially sticky icons, force fields and gravity wells.

The MouseField system is based on the *absolute control* or mapping used in ENLAZA. In fact, when the cursor is not under the influence of a button’s gravity well, there are no changes in the CD gain. The cursor is displaced with the user’s head movements depending on the maximum range of motion (*ROM*) established by the therapist.

There are three parameters to set up besides *ROM*: attenuation inside the gravity well, and its area of influence (defined by two distances):

- **Attenuation index inside the gravity well, AI .** The higher AI is, the more attenuated the movement of the cursor will be, as it will be attracted to the center of the button. While *dwell click* will be easier to perform with high values of AI , escaping from the button’s field (in situations in which the cursor got captured by an undesired button) will be harder. $AI = 0$ provides the traditional absolute control.
- **Minimum distance, D_{min} .** It fixes the distance to the center of one button in the screen where the cursor gets captured by the button’s gravity well. For instance, if the value of D_{min} is 50% of the button

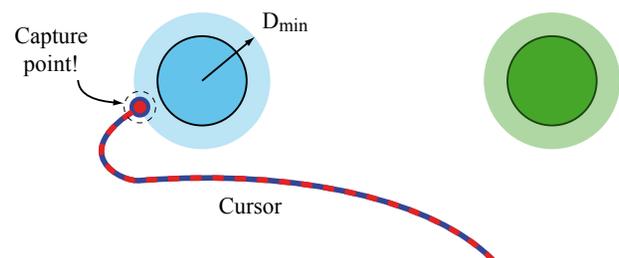


Figure 2. MouseField. The cursor gets captured by the button’s gravity field after entering a radius D_{min} .

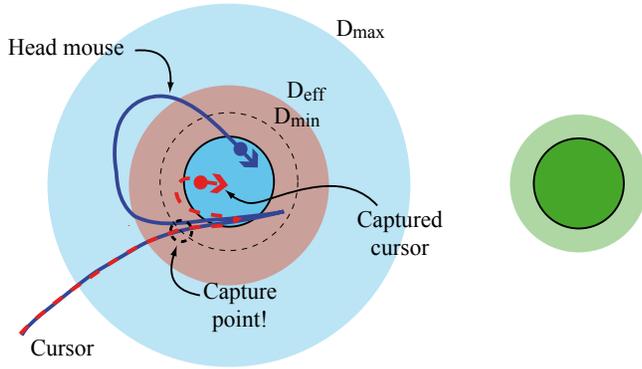


Figure 3. Representation of the effects of the gravity fields in the trajectory of the captured cursor. The dashed red line represents the resulting trajectory; the solid blue line, the trajectory the cursor would take in the absence of a gravity field.

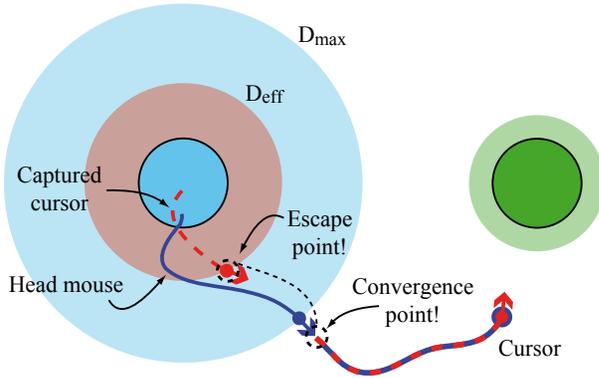


Figure 4. Representation of an escape maneuver. The captured cursor escapes the gravity field after reaching a distance of D_{eff} from the center of the button. Then, its location converges to the location of the head mouse, i.e. the cursor without the effects of the field.

size, the cursor will be affected by the gravity field just by touching the button's boundaries.

- **Maximum distance, D_{max} .** It is used to establish the distance (measured as a percentage of the distance between two adjacent buttons) where the cursor is able to escape the button's gravity well.

When the cursor is under the effects of one of the button's gravity field, as the one in Figure 2, its movement is attenuated. It is the same effect as augmenting the required *ROM*: the user will have to perform wider head movements to reach the same screen locations, and this

attenuation factor depends on the value of *AI*. Figure 3 depicts how the gravity well affects the cursor. The blue line represents the head mouse, i.e. the trajectory of the cursor if the user controlled the interface with the traditional algorithm. A typical CP user *overreaches* the button and starts some *erratic movements around the button* without actually hovering it the required time for a dwell click. The dashed red line shows the alternative trajectory: the user may have poor fine control and therefore be unable to stop the cursor over the target, but now that the gravity field is attracting the cursor, the user's uncontrolled movements will be attenuated and will not displace the captured cursor beyond the boundaries of the button. The user escapes the field as soon as a dwell click is completed or via an *escape maneuver*.

Figure 4 shows an example of escape maneuver from a gravity. In this scene the user was interested in reaching the green button but, due to some unfortunate movements, is trapped under the effects of the blue button's gravity well. In order to escape, the user must locate the captured cursor at a distance D_{eff} from the center of the button. Or, analogously, displace the head mouse outside a radius of D_{max} . Since the movement of the cursor is attenuated by a factor *AI* as a consequence of the gravity well, the value of D_{eff} is a function of D_{max} .

$$D_{eff} = \frac{D_{max}}{1 + AI} \quad (1)$$

Please note that when we mention D_{eff} , we are speaking about the trajectory of the captured cursor under the effects of the gravity field, while the term D_{max} is always associated to the movement that the user could produce in a head mouse that were not attenuated by the field. After escaping and converging to the location of the head mouse, the cursor and the graphical user interface return to their normal behavior. The convergence time depends on the filter used by ENLAZA; in the absence of that filter, the convergence would be instantaneous.

3. METHODOLOGY

3.1. Participants

Nineteen children and young adults with CP (ages 19.1 ± 10) from three centers specialized in CP and similar disorders, ASPACE Cantabria (7), ATENPACE (6) and Colegio de Educación Especial, CEE, of the Hospital de San Rafael (6) participated in the study. Two kind of users were recruited: those that could not access the computer with traditional input devices such as mouse and keyboards and those users that could access the computer correctly but would benefit of the physical activity that accessing the computer with a head mouse represents. A brief description of the user's motor skills

Table 1. Description of the participants: functional classification and preferred input device

User	MACS	GMFCS	Devices used
CP1	5	5	ET, HM, switch
CP2	4	4	ET, HM, switch
CP3	5	5	ET, HM, switch
CP4	5	5	ET, HM, switch
CP5	5	5	ET, HM, switch
CP6	5	5	ET, HM, switch
CP7	5	5	ET, HM, switch
CP8	5	5	Eye-tracker
CP9	3	5	Switch+plafons
CP10	5	5	None
CP11	4	5	Adapted mouse
CP12	5	5	Eye-tracker
CP13	4	3	Joystick
CP14	5	4	Touchpad, touchscreen
CP15	3	5	Mouse, keyboard
CP16	4	4	Touchscreen
CP17	5	5	Eye-tracker

* ET, eye-tracker; HM, head mouse.

and experience with computer interaction can be read in Table 1. Although there were no drop outs in the experiments, two of the participants were not able to use the interface without MouseField (the test will be described in detail in Section 3.4) and their data was not included in further analysis.

3.2. Design

The MouseField algorithm was integrated into a specific .NET C# application compatible with ENLAZA that was developed for the study. It consisted in a videogame based on reaching tasks with 12 levels of difficulty, corresponding

**Figure 5.** Werium wireless inertial measurement unit, WIMU. Werium Assistive Solutions S.L., Spain.

to 6 values of ID , that had to be completed with and without the MouseField facilitation system.

3.3. Apparatus

The participants wore the ENLAZA interface, depicted in Figure 5. All of them were sitting on their wheelchair during the work sessions, with the exception of CP16, that stood up during one session. No changes in task performance were found due to this modification. CP13 has two cochlear implants but they did not interfere the measurements of the inertial sensor either. All participants sit (or stood, in the aforementioned exception) in front of a 17 inches computer screen, at a distance of 50 cm approximately. Screen resolution was 1020x1280. MouseField had the following configuration for all the participants:

- AI : 3.0.
- D_{min} : 100% of the target size.
- D_{max} : 100% of the distance between targets.

3.4. Procedure

The standard work session is represented in Figure 6. It would generally take place after a 5 minutes training period with ENLAZA and non-related videogames that were use to check that the calibration process had been completed correctly and the participant felt comfortable with the interface. As proposed by the therapists, each of the participants was asked to perform a maximum of 72 reaching tasks divided in two phases of increasing difficulty:

- (i) **Interaction with ENLAZA and MouseField, group MF.** At the beginning of the session the participants had to perform $n = 6$ consecutive reaching tasks of amplitude A_1 and click in a target of diameter W_1 , corresponding to a value of $ID_1 = 1.58$ bits. After a few seconds to rest, a new set of targets of diameter W_2 separated by a distance of A_1 , corresponding to ID_2 would be placed in the screen. All the values of ID can be found in Table 2. After completing each level of difficulty, for a maximum of 6 levels ($ID_i, i \in \{1,6\}$) the user would enter the second phase. Of course, the user could choose not to continue with the session after finishing one level.
- (ii) **Interaction with ENLAZA only, group E.** This phase is a repetition of the first one except the user would no longer be helped by MouseField during the tasks. Our hypothesis is that the difficulty of the reaching tasks will augment significantly.

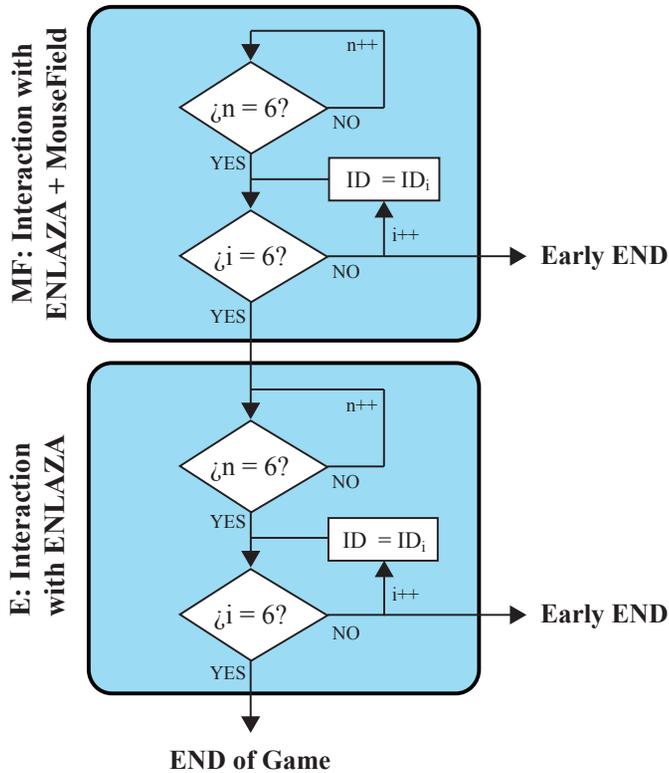


Figure 6. Test procedure. The participants were asked to perform six reaching tasks characterized by other six different values of ID using the ENLAZA interface with and without the pointing facilitation technique, MouseField.

As mentioned, the participants could have a break after completing any of the levels and were able to end their participation in the ongoing session if they felt they had reached their top. The duration of the work sessions was around 15-20 minutes.

3.5. Data analysis

3.5.1. Evaluation measures

A total of ten parameters were recorded or estimated for the analysis of the reaching tasks. We selected rapidity and

Table 2. Distribution of W , A and corresponding ID

Sublevel	W (px)	A (px)	ID (bit)
1	125	250	1.58
2	125	300	1.81
3	100	300	2.00
4	75	300	2.32
5	50	300	2.81
6	25	300	3.7

accuracy measures for the evaluation of the performance of users with various impairment levels due to CP in pointing tasks.

Rapidity measures:

- Average speed, AS (px/s),
- zero acceleration phases, ZA ,
- movement time, MT (s),
- throughput, TP (bits/s).

Accuracy measures:

- Trajectory length, TL ,
- index of horizontal component, IHC ,
- index of vertical component, IVC ,
- number of mistaken clicks per task, MC ,
- ratio of ranges of motion in the horizontal axis, ROM_r^x ,
- ratio of ranges of motion in the vertical axis, ROM_r^y .

According to [Almanji et al. \(2014\)](#), rapidity measures are affected by impairment level (MACS or GMFCS), but accuracy measures are not. [Velasco et al. \(2014\)](#) confirmed that rapidity measures depend on motor impairment and found that some measures such as ROM depend on the impairment profile (augmented or decremented muscle tone, presence of ballistic movements, etc.). The measures will be classified according with the way the participants interacted in the computer (using ENLAZA, E, or ENLAZA complemented with MouseField, MF).

3.5.2. Statistical Analysis

The evaluation measures were checked for normality by the Lilliefors normality test. If both groups passed the test, a paired t-test ($\alpha=0.05$) would be used to determine between group significance. If either group failed normality test, group significance would be determined by the non-parametric Wilcoxon signed-rank test ($\alpha=0.05$).

3.5.3. Exploratory analysis

Since the evaluation of the 17 participants individually would be virtually unmanageable, we used exploratory analysis to generate a reduced number of subgroups for further analysis. Data clustering was applied to the set of 10 parameters measured for each user and exercise. A *fuzzy c-means* clustering algorithm converged before a maximum of 200 iterations with a precision of 0.00005. The participants were grouped in 3 clusters according to the maximum membership estimated. Only the measures of the participants using ENLAZA (without MouseField) were used as input data for the algorithm. The module of the vector of centers, $|\vec{C}_i|$, is an indicator of the distance of the cluster i from the “average” measures. Similarly, euclidean distances between cluster centers

Table 3. Rapidity and accuracy measures for both ENLAZA and MouseField groups shown as mean \pm standard deviation.

	E	MF	p
	Mean \pm SD	Mean \pm SD	
Rapidity Measures			
AS (px/s)	7.37 \pm 4.03	6.82 \pm 3.48	n.s.
ZA	364 \pm 359	301 \pm 448	* \downarrow
MT (s)	31.7 \pm 47.5	27.2 \pm 37.5	n.s.
TP (bits/s)	0.25 \pm 0.20	0.54 \pm 0.77	n.s.
Accuracy Measures			
TL	28.4 \pm 18.1	18.7 \pm 20.8	n.s.
IHC	0.31 \pm 0.17	0.36 \pm 0.16	* \uparrow
IVC	0.18 \pm 0.07	0.19 \pm 0.08	n.s.
MC/Task	2.61 \pm 6.59	4.62 \pm 11.7	* \uparrow
ROM _r ^x	25.1 \pm 39.9	86.7 \pm 289.3	n.s.
ROM _r ^y	13.9 \pm 13.7	12.3 \pm 10.6	* \downarrow

Significance: n.s non-significant, * <0.05 , * <0.005

can be calculated to evaluate the dissimilarity between clusters.

Statistical analysis was performed to the measurements grouped in clusters in order to look for significance in the differences between the two groups (E and MF).

4. RESULTS

4.1. Evaluation measures

The mean values and standard error estimated for the rapidity and accuracy measures are depicted in Figure 7. Mean values of *ZA* are significantly smaller ($p<0.05$) in the MF group than in the E group (301 vs. 364). Mean values of *IHC* are slightly greater ($p<0.005$) in the MF group (0.31 in E vs. 0.36 in MF). The average number of mistaken clicks per task, *MC*, also increased ($p<0.005$) with the use of MouseField (2.61 vs. 4.62). This can be due to the presence of distractors with gravity fields. Finally, the estimated values of *ROM_r^y* show that movements are more efficient with MouseField in the vertical axis (25.1 vs. 86.7) with MouseField.

Table 3 illustrates the values estimated for each measure as mean value \pm standard deviation. The values of standard deviation of most parameters are relatively high, hence the necessity of statistical analysis.

4.2. Cluster analysis

The distribution of the participants in three clusters, as well as the estimated cluster centers (c_1 - c_{10}) is depicted in Figure 8. The participants in the study were grouped in C_1 (35.3%), C_2 (47.1%) and C_3 (17.6%) as follows:

- C_1 ={CP2, CP12, CP13, CP14, CP15, CP16}.
- C_2 ={CP3, CP4, CP5, CP6, CP8, CP9, CP11, CP17}.
- C_3 ={CP1, CP7, CP10}.

We estimated $|\vec{C}_1|=0.741$, $|\vec{C}_2|=0.385$ and $|\vec{C}_3|=1.817$. The euclidean distances between the different clusters are $d(\vec{C}_1, \vec{C}_2)=0.633$, $d(\vec{C}_1, \vec{C}_3)=1.659$ and $d(\vec{C}_2, \vec{C}_3)=1.776$.

The clusters were ordered according to the mean value of *TP* measured for the interaction with ENLAZA, E group: 0.59 bits/s, 0.23 bits/s and 0.07 bits/s for C_1 , C_2 and C_3 , respectively. Members of C_1 and C_3 were the most and least skilled.

The measured parameters for the cluster analysis can be observed in Table 4.

C_1 achieved the best results concerning rapidity and accuracy measures. Its members showed subtle increments in rapidity measures between the E and MF groups. *AS* increases from 8.84 px/s to 9.01 px/s, *ZA* rises from 102 to 126 and *TP* reaches 0.95 bits/s (MF) while the value obtained in the E group was 0.59 bits/s. These participants also obtained the best results in all accuracy measures in the E group, that revealed small increments in the MF group: mean values for the two groups were 15.50 and 19.20 (*TL*), 0.27 and 0.34 (*IHC*), 0.74 and 1.62 (*MC*), 15.60 and 21.70 (*ROM_r^x*), and 7.80 and 10.60 (*ROM_r^y*). The calculated mean value of *IVC* decreased from 0.26 to 0.23.

The participants in C_2 are the maximum contributors to the estimation of parameters presented in Section 4.1,

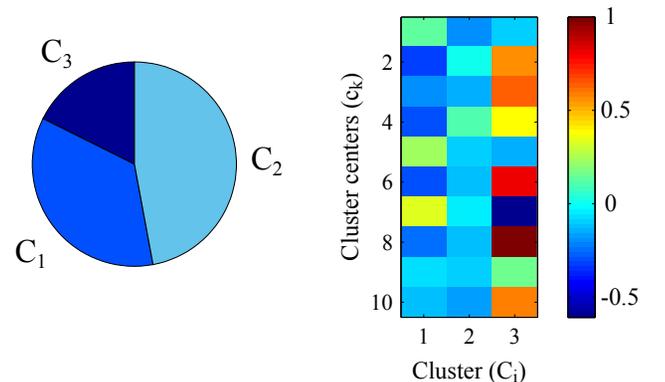


Figure 8. Results of fuzzy c-means clustering. On the left, groups and their size generated for the interaction with ENLAZA alone. On the right, localization (centers) of groups in a 10D space.

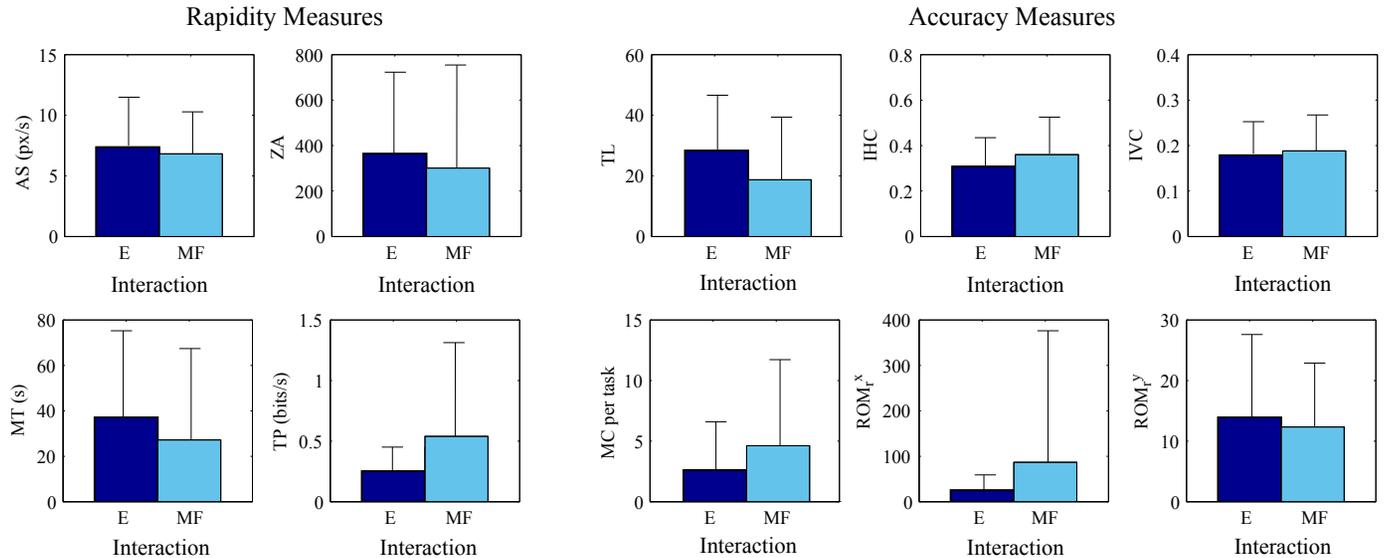


Figure 7. Mean values and standard error of the ten metrics estimated during reaching tasks performed by the participants using ENLAZA alone (dark blue) and ENLAZA complemented with MouseField (light blue).

thus the mean values of rapidity and accuracy measures measured for the total population and this cluster are similar. The calculated mean values of ZA , MT and TP were 484, 33 s and 0.23 bits/s in the E group. Accuracy measures in the same group were 0.37 and 1.63, corresponding to IHC and MC . The analysis of the MF group shows a decrement in ZA (295, $p < 0.05$) and MT (22.10 s, $p < 0.005$). Meanwhile, other measures such as TP , IHC and MC increased their mean values to 0.41 bits/s ($p < 0.005$), 0.42 ($p < 0.05$) and 3.49 ($p < 0.005$).

The members of C_3 exhibited the most erratic behavior in terms of rapidity in the E group: they reached the greatest mean value of AS (9.44 px/s) but the worst mean values of ZA , MT and TP : 940, 113 and 0.07 bits/s. They also registered the worst mean values of some accuracy measures such as IHC , IVC , MC and ROM_r^y . The estimated mean value ROM_r^x was slightly smaller than the one measured in C_2 : 26.5. The measurements in the MF group indicate a decrement in rapidity measures such as AS (8.19 px/s, $p < 0.05$), ZA (344, $p < 0.005$), MT (38.90 s, $p < 0.005$) and an accuracy measure, ROM_r^y (28.00, $p < 0.005$). Increments in TP (0.20 bits/s, $p < 0.005$) and IHC (0.39, $p < 0.05$) were measured.

Mean and standard deviation of the GMFCS and MACS scores for each cluster were calculated as well. The scores of GMFCS were 4.16 ± 0.75 , 5.0 ± 0.0 and 5.0 ± 0.0 for C_1 , C_2 and C_3 , respectively. MACS' scores for the same clusters were 4.16 ± 0.75 , 4.62 ± 0.74 and 5.0 ± 0.0

5. DISCUSSION

This study aimed to quantify the improvements in pointing tasks produced by a facilitation technique, MouseField, in a rather heterogeneous population such as users with CP and GMFCS and MACS levels III, IV and V.

In the initial phase, we quantified the effect that MouseField has on rapidity and accuracy measures calculated from a group of 17 children and young adults with CP and various levels of motor disorder. As we expected, we could not find significant differences between groups (E, MF) in most of the evaluation measures. This may be a consequence of the great heterogeneity and the reduced size of the sample. An interesting result is the fact that the number of mistaken clicks increased significantly with MouseField, direct consequence of the presence of distractors. Biswas and Langdon (2011) and Zhai et al. (2003) predicted their apparition, but only measured negative effects in the movement times.

The second phase of the analysis involved grouping the participants. Cluster analysis allowed us to categorize our participants in 3 groups based on task completion speed: slow, moderate, and almost normal. This approach lead to pointing out subtle differences between users, undetected otherwise. While members of C_3 improved their rapidity and accuracy measures with MouseField, members of C_2 were also faster but slightly less accurate, as they registered higher values of mistaken clicks. Interestingly, members of C_1 showed no signs of being faster and were significantly more inaccurate with MouseField.

Table 4. Rapidity and accuracy measures for both ENLAZA and MouseField groups shown as mean \pm standard error.

	C ₁			C ₂			C ₃		
	E	MF	p	E	MF	p	E	MF	p
	Mean \pm SE	Mean \pm SE		Mean \pm SE	Mean \pm SE		Mean \pm SE	Mean \pm SE	
Rapidity Measures									
AS	8.84 \pm 0.04 ^b	9.01 \pm 0.03 ^b	* \uparrow	6.17 \pm 0.05 ^a	6.10 \pm 0.05 ^a	n.s.	9.44 \pm 0.30	8.19 \pm 0.14	* \downarrow
ZA	102 \pm 3.90 ^{b,c}	126 \pm 2.99 ^c	* \uparrow	484 \pm 22.50 ^{a,c}	295 \pm 13.80	* \downarrow	940 \pm 45.57 ^{a,b}	344 \pm 18.59 ^a	* \downarrow
MT	10.50 \pm 0.21 ^{b,c}	11.80 \pm 0.19 ^c	n.s.	33 \pm 0.81 ^{a,c}	22.10 \pm 1.11	* \downarrow	113 \pm 4.75 ^{a,b}	38.90 \pm 1.59 ^a	* \downarrow
TP	0.59 \pm 0.01 ^{b,c}	0.95 \pm 0.08 ^c	n.s.	0.23 \pm 0.01 ^{a,c}	0.41 \pm 0.01	* \uparrow	0.07 \pm 0.01 ^{a,b}	0.20 \pm 0.02 ^a	* \uparrow
Accuracy Measures									
TL	15.50 \pm 0.45 ^{b,c}	19.20 \pm 0.62 ^c	* \uparrow	42.6 \pm 1.49 ^a	50.80 \pm 2.94	n.s.	264 \pm 13.51 ^a	98.60 \pm 4.93 ^a	n.s.
IHC	0.27 \pm 0.01 ^b	0.34 \pm 0.01 ^b	* \uparrow	0.37 \pm 0.01 ^a	0.42 \pm 0.02 ^a	* \uparrow	0.38 \pm 0.01	0.39 \pm 0.02	* \uparrow
IVC	0.26 \pm 0.01 ^b	0.23 \pm 0.01	* \downarrow	0.18 \pm 0.01 ^a	0.20 \pm 0.01 ^c	n.s.	0.18 \pm 0.01	0.20 \pm 0.01 ^b	n.s.
MC	0.74 \pm 0.02 ^{b,c}	1.62 \pm 0.03 ^c	* \uparrow	1.63 \pm 0.04 ^a	3.49 \pm 0.20	* \uparrow	8.37 \pm 0.64 ^a	6.56 \pm 0.24 ^a	n.s.
ROM _r ^x	15.60 \pm 0.59 ^{b,c}	21.70 \pm 1.25	* \uparrow	28.7 \pm 2.18 ^a	70.90 \pm 9.26	n.s.	26.50 \pm 1.20 ^a	18.0 \pm 0.93	* \downarrow
ROM _r ^y	7.80 \pm 0.33	10.60 \pm 0.45 ^c	* \uparrow	8.18 \pm 0.30	7.84 \pm 0.36 ^c	n.s.	30.20 \pm 3.03	28.0 \pm 1.37 ^{a,b}	n.s.
Significance (E from E & MF): n.s non-significant, * <0.05, * <0.005									

^a Significantly different from C₁

^b Significantly different from C₂

^c Significantly different from C₃

5.1. The improvements in rapidity and accuracy

Most of the studies enumerated in Section 1.1 reported the values of movement times and error rates in order to assess improvements in rapidity and accuracy. While we calculated 8 more measures, we will reevaluate *MT* and *MC* for the sake of comparison.

Mousefield enabled significant reductions of *MT* (33.3% and 65.5%) for the clusters C₂ and C₃. The reductions in movement times for similar facilitation techniques were 74% (object pointer), 50% (area cursor) or 30% (bubble cursors). Other methods achieved milder reductions: 17.3% (force fields), 16.9% (semantic pointing), 3-12% (expandable buttons) and 8.2% (angle mouse).

We found that MouseField doubled the error rate (measured with *MC*) of ENLAZA in clusters C₁ and C₂. Other techniques performed better: force fields, bubble cursors and angle mouse reduced error rates in 79%, 62% and 18%, respectively. Expandable buttons reduced error rates for low values of *ID* but, similarly to our method, registered increments in the error rate around 38% for the highest indexes of difficulty. The rest of the studies did not report results concerning accuracy.

5.2. The relation between functional scores and improvement

Even though clinical scores such as GMFCS or MACS are only valid for people under 18 years old, the fact is that they provide useful descriptive information and that the results that a person would achieve in any of those scales would not vary significantly after become 18.

As we expected, there was a relation between the scores achieved in MACS and GMFCS and the benefits provided by the use of MouseField. Those participants that scored worst in functional scales were grouped in C₂ and C₃, and improved their with MouseField. On the contrary, those users with better scores in MACS and GMFCS were grouped in C₁ and the results showed that MouseField did not enhance their performance and even limited their accuracy. The fact that users in C₂ and C₃ scored similarly in MACS and GMFCS but had very different task performance shows that functional scales lack the resolution needed to detect relative small changes in motor function.

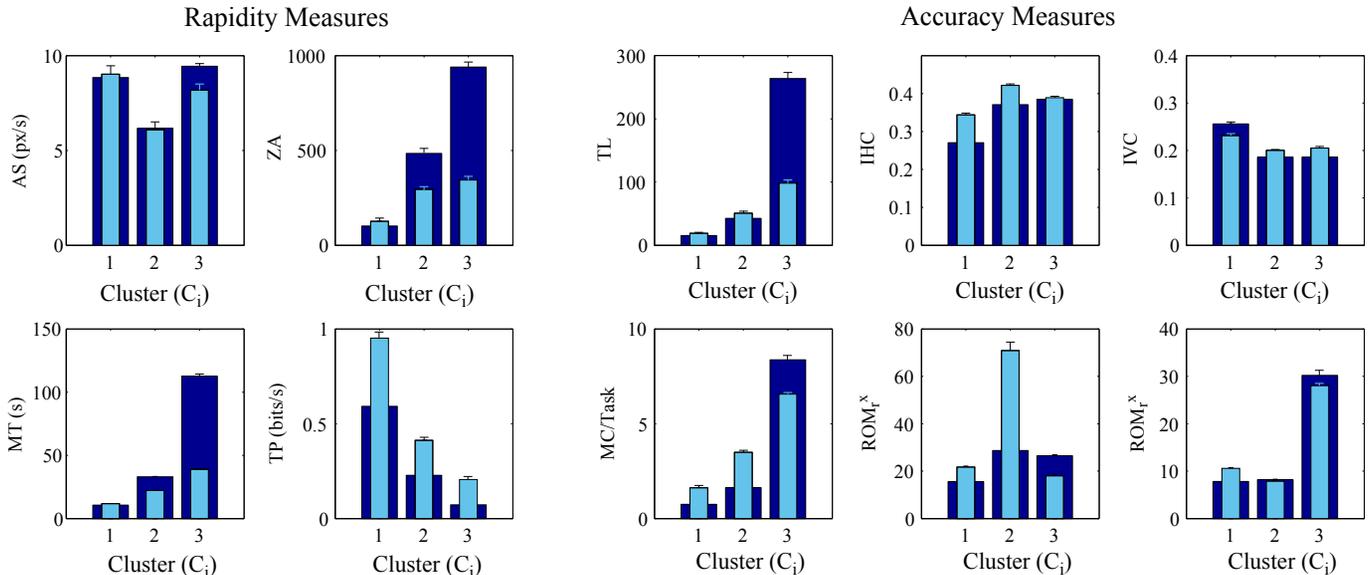


Figure 9. Mean values and standard error of the ten metrics estimated during reaching tasks performed by the participants using ENLAZA alone (dark blue) and ENLAZA complemented with MouseField (light blue) classified in 3 groups, C_1 - C_3 , after the cluster analysis.

5.3. The effects of ENLAZA and MouseField on navigation and targeting

The participants in this study showed signs of two kind of motor limitations: ballistic uncontrolled movements that limited their navigation skills and serious difficulties maintaining head posture. Raya et al. (2012) presented ENLAZA (formerly named ENLAZA) and implemented a Robust Kalman Filter that was configured to minimize the influence of such involuntary movements in the trajectory of the cursor. Velasco et al. (2014) measured task performance of children with CP using ENLAZA during reaching tasks and confirmed that poor performance was not due to the presence of ballistic movements, i.e. navigation problems.

Our results showed a marked improvement in rapidity and accuracy due to MouseField in most of the participants. Assuming that ENLAZA resolved most of the navigation problems, we can conclude that MouseField influenced targeting errors mainly. Since all the participants used the same field configuration parameters, it is yet unclear how they influence user performance individually. A systematic analysis is needed in order to find values of D_{max} , D_{min} or AI to minimize the effects of distractors without affecting the improvements in rapidity and accuracy that MouseField provides.

During the experiments, we observed that distractors could capture the cursor even if the trajectory or the cursor was tangential to the area of influence of the

distractor. Thus, it would be interesting to exchange the static attenuation index by a new dynamic attenuation function, $AI(d)$. The new $AI(d)$ would decrease with the distance to the center of the button, hence minimizing the effect of that kind of distractors in the trajectory of the cursor.

5.4. The use of cluster analysis as exploratory tool

Cluster analysis provided us with a new point of view and statistical significance was easier to find.

There are recent precedents of cluster analysis applied to the categorization of CP. Sangeux et al. (2015), Roche et al. (2014) and Toro et al. (2007) evaluated sagittal gait patterns. Others, such as Stevenson et al. (2006) assessed growth patterns. The sizes of their datasets were 44 (Roche et al.), 56 (Toro et al.), 273 (Stevenson et al.) and 776 participants (Sangeux et al.); the number of clusters estimated, 3 (Stevenson et al.), 5 (Roche et al. and Sangeux et al.), and 13 (Toro et al.).

Even though our estimations indicated that 6 clusters would be “optimal”, precedents such as Roche et al. (2014) support our partition in three main clusters. In their study, they categorized gait patterns of 44 adults with CP into 5 clusters among which 3 subgroups could be determined based on gait speed. In addition, this approach prevented us from including clusters with less than 3 members in our analysis.

5.5. Experimental concerns and further work

There are some limitations that are inherent to the population under study and the experiment itself. To begin with, the participants in the study did not have similar experience with technology: while some of them had little or no skills regarding the use electronic devices, others used them on a daily basis. What is more, the participants in ASPACE Cantabria were very experienced in the use of ENLAZA. In order to minimize this contrast, we organized two special training sessions with ENLAZA in Atenpace and CEE Hospital de San Rafael.

Secondly, we designed our work session as a videogame with 12 levels of difficulty that had to be played and completed sequentially. This design maximized the entertainment of the participants and, consequently, their adherence to the study. Unfortunately, it could also have influenced the results since we are unsure about how the order of the interaction method (using MouseField before or after the interaction with ENLAZA only) affects the performance of the participants.

Finally, the sample size is always an issue with populations with this degree of heterogeneity in aspects such as muscular tone, postural control, involuntary movement and intellectual ability. We designed a 3-center study that would allow us to recruit 17 participants, a number that is well above the sample size of similar studies: Keates et al. (2000) recruited 4 people with athetoid CP and another with Friedreich's ataxia (FA); Hwang et al. (2003), 7 users with CP and 1 with FA. Wobbrock et al. (2009) included 2 users with FA and another one with CP. Olds et al. (2008), Ding et al. (2015) and Biswas and Langdon (2013) collected the data from 3, 7 and 5 people with athetoid CP to build their models. Nevertheless, it would have been desirable for us to have clusters with more than 5-10 members in order to strengthen our findings.

To gather a larger CP group to take part in a series of systematic tests not based on increasing difficulty would be desirable for more robust statistical significance but that can only be achieved if we succeed to integrate this kind of exercises into these users' daily routines.

6. CONCLUSION

In our experiment, we used data clustering to categorize a group of 17 children and youths with CP in 3 main groups and analyzed how MouseField, a pointing facilitation algorithm, influenced the way they interact with the computer via ENLAZA, an inertial interface based on head movements.

While recent studies proved that ENLAZA took care of navigation problems usually found in users with motor disorders, we found that MouseField can be the

solution for targeting errors due to poor posture control. Unfortunately, the facilitation algorithm can be a burden more than a help for some users that are experienced enough in the use of ENLAZA and have good postural control.

MouseField, as target-aware pointing technique, faces two main challenges for its implementation in real-world applications that will limit its effectiveness. First, it needs reliable information about the size and location of interface elements. Second, further works on the escape maneuvers, optimum values for the configuration parameters and the design of dynamic attenuation functions inside the area of influence of the gravity wells are needed in order to minimize the undesirable effects of any possible distractor.

Although further exploratory analysis and the design of new models of interaction of users with CP are needed in order to better understand how these algorithms can be customized for users with different profiles of motor disorders, we are confident that combining ENLAZA for the ballistic phase and MouseField for the homing phase can be the key for functional compensation systems in HCI.

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