Longitudinal Study of Two Virtual Cursors for People With Motor Impairments: A Performance and Satisfaction Analysis on Web Navigation

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ABSTRACT The lack of dexterity in the upper limbs of people with motor impairments may prevent the use of standard pointing devices, such as mice, to access graphical user interfaces. In these cases, pointing and clicking are usually performed by means of alternative devices such as joysticks, trackballs or standard keyboards. However, target acquisition can still be challenging for this group of people due to their physical condition. Based on previous works, we developed two virtual cursors: the novel cross cursor and the standard area cursor. They are devoted to assist two different groups of users with link selection within web pages: keyboard-only users, and joystick and trackball users, respectively. Both virtual cursors have been evaluated and compared with the original unassisted cursor in a longitudinal study. Eight people with motor impairments participated in an unsupervised experiment from their own personal computers at home. For a period of six weeks, each participant used both a virtual cursor and the original unassisted cursor to freely navigate the Web, and to perform predefined target acquisition tasks. Interaction data was automatically logged throughout the study along with subjective assessments concerning the usability of the virtual cursor being tested. Results show significant improvements for both virtual cursors in six of the seven cursor parameters studied, albeit with performance variations between some participants. The virtual cursors were extensively used for free web navigation and in their subjective assessments both were positively endorsed by participants who also put forward improvement suggestions for future developments.

INDEX TERMS Alternative pointing devices, human performance, longitudinal study, people with motor impairments, user satisfaction, virtual cursors, web accessibility.

I. INTRODUCTION

Computer access is often depicted as an act of pointing to and selecting graphical elements on the screen [1]. People with motor impairments (MIs) in their upper limbs may suffer from conditions such as poor coordination, slow movements, low strength, tremors, spasms, rapid fatigue, or difficulty controlling direction or distance, that hinder these actions in different ways [2]. These conditions may prevent the use of standard pointing devices [3] for activities such as navigating the Web.

In the last two decades various alternatives to the standard mouse have been developed to enable people with MIs

The associate editor coordinating the review of this manuscript and approving it for publication was Young Jin Chun [ID].

to access graphical user interfaces (GUIs). These assistive technologies (ATs) seek to meet the special needs of this heterogeneous group of users who cannot grip or control standard mice [4], [5]. The most commonly used ATs to overcome this issue include specific alternative pointing devices (e.g., trackball or joystick), software applications such as mouse keys that enable the use of keyboards as an alternative to a mouse, or devices to support alternative manipulation (e.g., head wands or mouth sticks). Although these mouse alternatives allow people with MIs to interact with the on-screen cursor, performing point and click tasks is still difficult in many cases. Accordingly, Keates *et al.* [6] detected that users with MIs had to make an additional effort to plan and control physical movements resulting in them being 50% slower than their counterparts without motor disabilities.
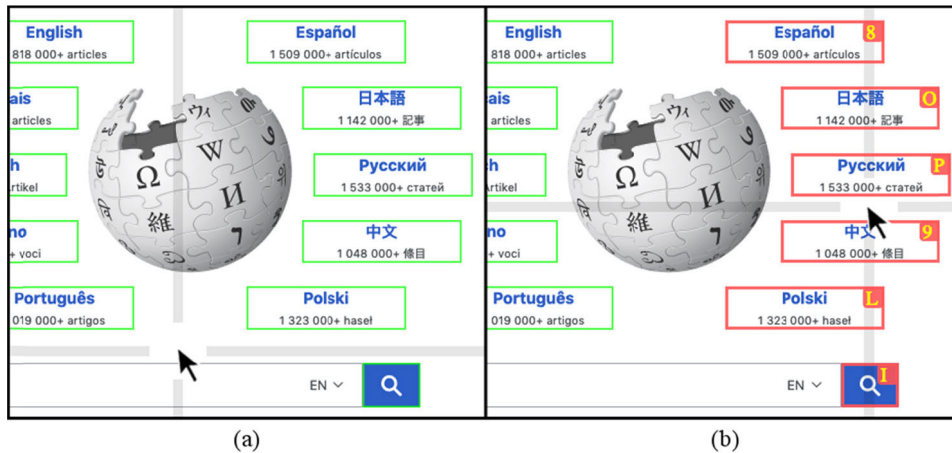
FIGURE 1. a) The cross cursor with no links within reach from its current location, therefore no shortcuts are available to assist target selection. b) After diagonally moving the pointer up to the right, 6 links are within reach of the cross cursor via single-key shortcuts.

Other authors also found pointing and clicking actions to be less precise and more time consuming for people with MIs [7]–[17].

Pointing actions require the user to move the cursor to a particular target on the screen. These actions consist of an initial phase of ballistic movements followed by a slower homing phase until the cursor is positioned on the desired target [18]. Positioning errors [19] may occur, including additional sub-movements, movement direction changes, and indirect motion towards a target. In addition, targets can also be missed when the mouse pointer enters and leaves a target multiple times. Clicking actions require the user to press and release a button while holding the cursor over the target [9] thereby completing the selection process [18]. As with pointing actions, errors may also occur in clicking tasks. These errors include moving the cursor during an ''attempted click'' and ''extended clicks'' [19].

Several research works have been carried out to mitigate the effects of pointing and clicking errors. Ivory *et al.* [20] opined that most developments were focused on vision related issues leaving the needs of users with MIs insufficiently supported.

Various authors approached the development of alternative hands-free interaction mechanisms in order to reduce the effort required from people with MIs when carrying out pointing and clicking tasks in GUIs. Some examples are vision-based user interfaces that automatically recognized facial gestures [21], head mice that allow head movements to control the cursor [22], voice-based mouse pointer controls [23]–[25] or head-operated devices [26]. There are also works oriented towards implementing new alternative input devices such as the 2-D haptic device [27], an assistive robotic aid to minimize the absence of motor control in the upper limbs. However, Almanji *et al.* [7] argued that the use of AT for computer access has encountered barriers that have led to the use of standard mice or touch screens for practical

reasons, mainly a lack of training and the elevated costs of some solutions. Virtual enhancements that modify the standard behaviour of the cursor to assist pointing and clicking tasks [1], [28]–[35] would appear to be more affordable solutions. Our work is underpinned by the conviction that further research is needed to improve assistive virtual tools due to the heterogeneous characteristics and needs of people with MIs.

People with MIs may face similar difficulties in pointing and clicking tasks depending on the mouse alternative being used. For instance, previous behavioural studies in GUIs by users with MIs [14]–[16] showed that keyboard-only users are more affected by total distance to the target, whereas joystick and trackball users tend to have accuracy issues when bringing the cursor to a halt over the target. Based on those findings, we developed two specific virtual cursors for assisting link selection on the Web: the novel cross cursor (Fig. 1) for keyboard-only users, and a standard area cursor (Fig. 2) for joystick and trackball users. Initially, both virtual cursors were tested with real users in a single-session supervised web-based experiment. It showed that both groups benefited from their respective assistance method for link selection, both in terms of user satisfaction [36], [37] and performance [38]. This study also suggested there was an improvement in performance with frequent usage of the virtual cursors. These results confirmed the need to continue the search for solutions to improve assistance on point and click tasks for this group of users. The importance of the Web for the personal autonomy of people with MIs underscores the need to continue researching web browsing assistance.

The main contribution of this paper is to explore the long-term benefits of both the aforementioned virtual cursors (the cross and area cursor) in a longitudinal study on the Web with real users with MIs. We conducted a six-week remote study in which eight users of alternative pointing devices (including keyboard, joystick and trackball) participated from home, obtaining in this way more naturalistic interaction
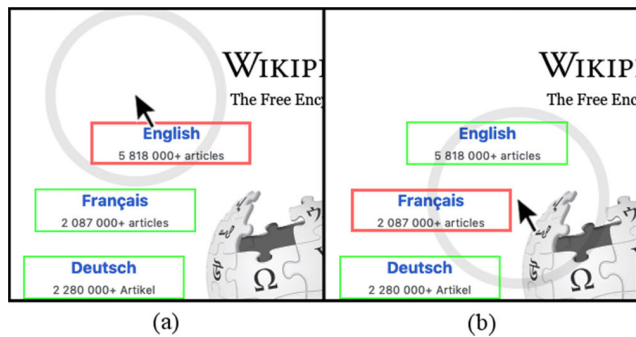
FIGURE 2. a) The area cursor being tested enables the highlighted link to be clicked without needing to hover the cursor pointer over it. b) If the activation area includes more than one link, the nearest one to the pointer can be selected from a distance.

data from everyday computer use. Our goal was to study their performance with both the virtual cursors in comparison with the original unassisted cursor (from now on referred to as "original cursor") and the influence of distractors (i.e., other nearby links) on target acquisition on the Web. We also reported on the learning effect on performance with each cursor, user behaviour in free navigation, and participant satisfaction with the virtual cursor being tested.

The rest of the paper is organized in this way: Section II presents first several longitudinal studies that explore user behaviour and learning effects in interaction with computers, and then describes some well-known cursor enhancements for point and click assistance. Section III explains the implementation and functioning of both the virtual cursors being evaluated. Section IV details the methodology followed in the study. Section V describes the results regarding the performance and satisfaction of participants with the different variants tested. Section VI includes a discussion of the results. Section VII presents the conclusions.

II. RELATED WORK

A. LONGITUDINAL USER STUDIES

Longitudinal studies provide a feasible way to record users' interactions over extended periods of time, allowing users' behaviours and their evolution over time to be studied. Longitudinal studies also allow naturalistic data to be obtained when carried out remotely and unobtrusively without the participants moving from their familiar environment [39]–[41]. For this reason, we carried out a longitudinal study with real users in order to explore the learning effect on their performance and satisfaction with the two virtual cursors.

Longitudinal studies have not been extensively used because they are time consuming and more difficult to perform. Nevertheless, we adopted a longitudinal study methodology for analysing the behaviour of users when interacting with the Web, as laboratory experiments do not always provide reliable results about the use and adoption of assistive tools. The number of participants and the duration of longitudinal studies vary notably depending on their purpose and characteristics. Longitudinal studies found in the literature

focusing on people with special needs usually include far fewer participants than studies with people without impairments. This is due to the difficulty of recruiting samples of users with the required characteristics and to the complexity of the experiments.

Some longitudinal studies have analysed web accessibility problems from the perspective of blind users, and explored their performance in different situations. Bigham *et al.* [42] conducted a remote study over a period of one week with 10 blind and 10 sighted participants to evaluate differences in the browsing behaviour of these two groups. To this end a tracking proxy was used to remotely record both the visited pages and the actions taken by users on the web pages that they visited. For our experiment we adopted a similar data gathering scheme, but we used a client tool and a remote server to manage logged data instead of a proxy. Nicolau *et al.* [43] carried out a longitudinal study with five blind novice smartphone users to develop a richer characterisation of everyday typing performance on touchscreens. For eight weeks, in-situ device usage data was collected and weekly laboratory text-entry evaluations were conducted. Obtained performance measures include touch behaviours (e.g., touch contact points, exploration movements, and lift positions), character-level errors, and learning experience. In our experiment we also analysed performance and behaviour data focused on users with MIs.

Longitudinal studies have also been carried out with users with MIs to evaluate alternative input mechanisms. Mahmud *et al.* [24] conducted a comparative longitudinal study of two voice-based cursor control systems to get better understanding of novice users' experience over time. Ten participants were recruited for a longitudinal experiment over five consecutive days. In each experimental session participants had to complete 96 target acquisition trials with each cursor control system, as well as providing subjective ratings of each cursor modality in terms of their ease of learning, ease of use, level of fatigue, level of frustration, satisfaction and confidence. In order to characterize the pointer movement under each modality six different measures were analysed including target re-entry, task axis crossing, and movement error. Results showed that quantitative measurements as well as subjective ratings improved with time. This study was extended to people with MIs by Harada *et al.* [25]. They evaluated the learning curve for one of the systems involved in the previous study, the vocal joystick, in another longitudinal study with five participants with MIs and four participants without MIs. For our experiment we designated predefined tasks (adding free navigation) and also gathered subjective assessments. Sporka *et al.* [44] investigated the usability of a novel text entry application for users who cannot access a manual keyboard by gauging first impressions and how users adapted over time to the new system. To this end, a longitudinal study was conducted with five users with MIs. Participants were asked to use the tool for a minimum of 30 minutes each day, over the course of seven days. Their performance was measured on example phrases, and their

subjective assessments were collected in several interviews (pre-test, first-impression, post-test). The study reported that all participants improved their text entry rates with the tested system during the course of the experiment. In this experiment the peak performance did not outperform other solutions. In our study, the participants achieved better results with the proposed virtual cursors than with the original one.

B. ASSISTED POINT & CLICK

Much research has been done to facilitate target acquisition in GUIs, even though little of it has been specifically focused on assisting people with MIs to navigate the Web. The following works proposed some well-known cursor enhancements to assist point and click interactions, although these were not always initially aimed at people with MIs. Even if these works were not focused on assisting web browsing, some can be directly translated to this scenario and have served to define the basis of our research.

The steady clicks assistance [34] suppresses accidental clicks and slipping when clicking by freezing the cursor during mouse clicks. In this way, it prevents overlapping button presses and cancels clicks made while the mouse is moving at a high speed. Evaluations showed that this option improves time performance and that users with MIs required fewer attempts to select targets; moreover, participants expressed their preference for this assistance (9 out of 11) over the unassisted condition. This assistance aims to reduce clicking errors of people with MIs; however, it may not be useful for keyboard-only users as it was designed for a pointing device such as the mouse.

The angle mouse [45] is a pointing facilitator that attempts to improve target acquisition by adjusting the mouse control-display gain based on the deviation angles of the cursor path during movement. Thus, unlike most cursor enhancements, this technique (like the steady clicks) is based solely on the user's behaviour and requires no information from the targets on the GUI. Published results proved that this alternative improves the pointing performance of users with MIs while remaining unobtrusive for people without impairments. However, no alternative input device was tested as all the study participants (both with and without MIs) used a standard mouse to complete the experimental tasks.

Wobbrock and Gajos [35] suggested that difficulties faced by people with MIs could be alleviated by a different target acquisition paradigm called goal crossing. In this proposal users do not aim at a restricted area, but instead pass over a target line to perform a selection. Empirical results indicated a preference for goal crossing among people with MIs, although error rates were higher with this alternative. The authors also presented some design principles for this new target acquisition paradigm, but these are not usable on standard web interfaces.

Hwang *et al.* [30] studied the performance of users with and without MIs in a point and click task with targets modelled as virtual gravity wells. Their results showed the greatest improvements for the users with the most severe
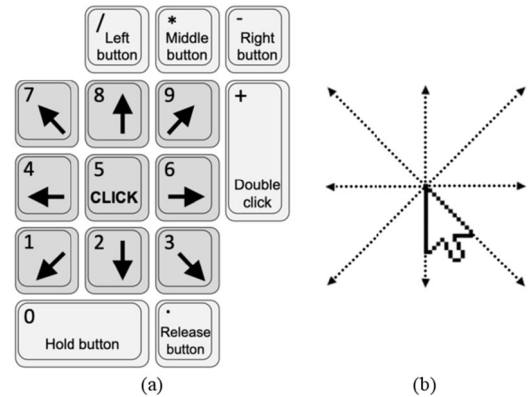

FIGURE 3. a) The mouse keys application allows the user to point and click with the on-screen cursor by using the highlighted keys of the numerical keypad. **b)** Eight possible paths that the cursor can travel from its current position with mouse keys.

impairments, even when multiple on-screen targets were haptically enabled. This technique looks promising for complex GUIs with numerous targets, as are the majority of web interfaces. More testing would be required in order to adopt it because it was only tested with a standard mouse, and no subjective perception from participants about the tested enhancements was published.

Worden *et al.* [46] studied the effectiveness of two interaction techniques: the area cursor (our circular version for the Web was inspired by this squared version) and the sticky icons, for improving the performance of older adults (with declined motor abilities) in basic selection tasks. The area cursor, successfully tested previously with people without MIs [47], uses a cursor with a larger than usual activation area. The latter technique makes an icon "sticky" by automatically reducing the cursor's gain ratio (number of pixels moved in response to a single increment of movement by the physical device) when it is over a target icon. Both techniques improve pointing time. The area cursor is especially useful when the icons are not too close together and also when the target size is small. The results showed that neither technique hindered performance in difficult situations (e.g., closely spaced targets). Other authors have studied variations of the area cursor, by dynamically resizing the cursor's activation area [28], or with different combinations of visual magnification or goal crossing [31], [32], [48]. The results from these works generally revealed improvements in performance, although the trials were mainly based on users without MIs, the only pointing device used was the mouse and sometimes participants did not prefer the proposed method.

Felzer *et al.* [49] compared two different methods for mouse emulation with the DualPad numeric keypad. The first method, called CKM, allows the mouse pointer to be moved in cardinal directions and to be clicked in a similar way to the mouse keys application (Fig. 3). The second method, called the DualMouse, does not rely on mouse movement at all, but directly clicks at a destination location following a step-by-step locating process. Evaluation based on a case study with

a single user with MIs revealed that the CKM method produced higher throughput than the DualMouse. Surprisingly, no cursor enhancement has been studied to assist pointing and clicking interactions of keyboard-only users applying mouse keys (Fig. 3) included in every major operative system. A Mozilla Firefox add-on, Vim Vixen[1], enables web browsing by using only the keyboard. This application labels every link on the visited web page with different shortcuts. Links are selected by typing the corresponding sequence of letters without having to use the cursor. For our experiment, we designed an enhanced version of this method. The cross cursor reduces the length of shortcuts to only one key by combining cursor movements to label just those links within reach of the virtual cursor (Fig. 1b).

III. VIRTUAL CURSORS FOR THE WEB

As we observed in previous works [14]–[16] about pointing and clicking behaviours of people with MIs, difficulties faced by participants varied depending on the alternative pointing device used. Thus, keyboard-only users were especially affected by the total distance from the starting point to the target (i.e., the pointing trajectory), whereas users of specific alternative pointing devices, such as joysticks or trackballs, had problems to halt the cursor over the target due to a lack of accuracy. In order to study empirically if these issues can be alleviated in web browsing, we developed two virtual cursors, implemented as browser add-ons, in order to test them with real users: the novel cross cursor (Fig. 1) and a standard area cursor (Fig. 2).

A. THE CROSS CURSOR

This virtual cursor aims to assist link selection on Web interfaces by reducing cursor displacement required for pointing. This is achieved by combining cursor movement and providing single-key letter shortcuts to every link within reach of the cross cursor (Fig. 1a and Fig. 1b). Links within reach of this virtual cursor are those traversed by the cross cursor lines. During its movement the cross cursor continuously displays a horizontal and a vertical line (that respectively extend over the entire width and height of the web page) crossing perpendicularly below its current position (Fig. 1). Shortcuts are automatically assigned and displayed next to every link within reach of the cross cursor when the virtual cursor comes to a halt and disappear whenever the cursor starts moving again. Single-letter shortcuts (together with number keys) are automatically assigned in order of proximity to the cursor pointer, starting from the right of the keyboard, with the closest keys to the numeric keypad first and the furthest to the left at the end. If all letter and number keys (36 in our case) have already been assigned in this way, the additional links within reach of the cross cursor will not have any shortcut assigned, requiring the cursor pointer to be brought nearer to display a shortcut. We used fixed values (10 px width and

90% translucent grey colour) for the visual appearance of the cross cursor lines.

The mouse keys feature, included on every major operative system, allows keyboard-only users to use the numeric keypad as a mouse alternative (Fig. 3a) by pressing the central '5' key for cursor clicking, and the surrounding number keys for moving it in vertical, horizontal and diagonal directions (Fig. 3b).

B. THE AREA CURSOR

This virtual cursor corresponds to the standard area cursor and aims to assist target acquisition on the Web by reducing the accuracy required to click a link. As it moves the area cursor continuously displays a circle of fixed size that is always centred on the current position of the pointer (Fig. 2) and which corresponds to its activation area. In this way, the closest link within its activation area can be clicked (see highlighted targets in red in Fig. 2) without needing to hover over it. We used fixed values for the visual appearance of the area cursor (10 px width and 90% translucent grey colour) as well as for the activation area diameter (130 px).

C. IMPLEMENTATION

Both virtual cursors were implemented using Scalable Vector Graphics (SVG) to display the corresponding visual elements (lines, circles, rectangles and letters) on the browser window, along with JavaScript to handle users' interactions with the cursor and the web content. To this end, the add-on that implements each virtual cursor is in charge of parsing every visited web page to find every link. The information about the location and size of each visible link within a page is processed by the add-on, which also handles users' interactions (mouse moves, clicks, and keystrokes) to modify standard pointing and clicking and assist target selection. To explore the long-term benefits of both virtual cursors in this longitudinal study we implemented some upgrades with respect to the previous versions tested on a single-session supervised study [36]–[38]. These included processing hidden and overlapping links in different layers (e.g., dropdown menus of navigation bars), as well as a command to allow users to deactivate and reactivate the virtual cursor at any time during web browsing (Fig. 4).

IV. METHOD

We conducted a longitudinal study on the Web with people with MIs in order to explore the satisfaction and performance achieved with the two virtual cursors in comparison with the original cursor. During a period of 6 weeks, we collected usage data of the three cursors tested (original, area and cross). During this period participants used their own personal computers at home to perform unsupervised tasks. This study was approved by the "Ethics Committee for Research Involving Human Beings" (CEISH) of the University of the Basque Country (UPV/EHU) that reviewed the purpose and methodology of the experiment and authorized us to collect and analyse the resulting data.

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[1] https://addons.mozilla.org/en-US/firefox/addon/vim-vixen (accessed on April 10, 2020)
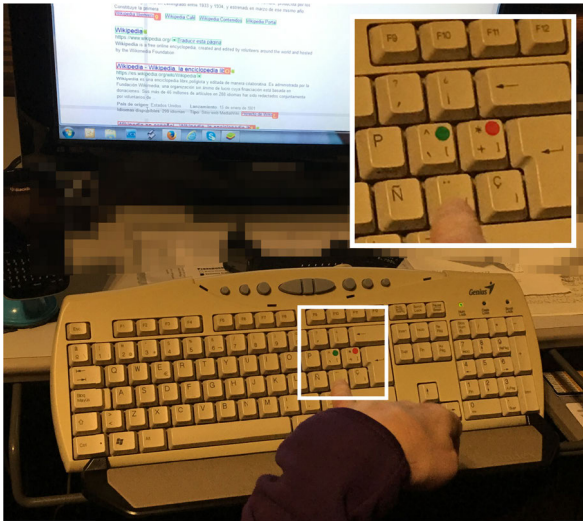
FIGURE 4. A keyboard user practicing with the cross cursor during the first visit to her house. Enlarged detail of the keyboard on the upper right corner shows the two keys tagged that were used on the experimental web browser to activate/refresh and deactivate the virtual cursor during free navigation.
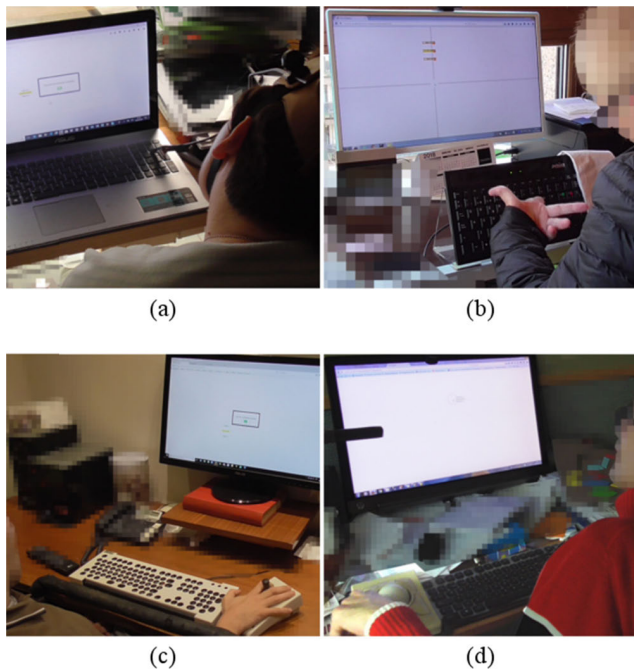

(a)   (b)

(c)   (d)

FIGURE 5. Four participants performing a supervised task during the first home visit of the longitudinal study: a) a keyboard user interacting through a head wand with her laptop, b) a keyboard user interacting directly with her hand, c) a joystick user, and d) an oversized trackball user.

A. PARTICIPANTS

Eight participants took part in this longitudinal study, all of them people with MIs involving limited dexterity in their upper limbs that prevent them from using a standard mouse (Fig. 5). According to Lazard *et al.* [50] this number of participants is generally acceptable for research focusing on users with a specific disability. In our study, all the participants

were regular computer users and were selected based on the alternative pointing device they used for target selection in GUIs. In this way, the following 2 groups were defined, each as the target group of a virtual cursor:

- *Keyboard users group (KU group)*: 4 keyboard users (mean age = 52.5 years, SD = 8.3) to test the cross cursor.
- *Joystick and trackball users group (JU group)*: with 4 participants, 3 joystick users and 1 trackball user (mean = 46 years, SD = 2.9) to test the area cursor.

Two participants from the KU group (K1 and K2) needed a head wand to interact with the keyboard, whereas the other two were able to push the keys directly with their fingers. Table 1 shows detailed information about the participants.

B. APPARATUS

All participants used their own personal computer at home. All of them used a desktop computer except participant K1 who owned a laptop computer. The operative system running on each computer was a version of Windows7 (K3, K4, J1, J2 and J4) or Windows10 (K1, K2, J3). Table 1 includes display sizes and resolution used by each participant.

The RemoTest platform to design and perform remote user tests [15], [51] was used to conduct this unsupervised longitudinal study. A secure server was in charge of running the remote modules of the RemoTest platform, both to gather interaction data from each participant and to provide them with the target acquisition tasks that had to be repeated regularly. Additionally, we installed the Mozilla Firefox web browser (version 44.0.1) on each participant's computer, personalized with two add-ons: one corresponding to the virtual cursor to be tested, and the other one implementing the Participant Module of the RemoTest platform. This module was in charge of communicating the experimental browser with the remote modules of RemoTest to identify each participant, present them with the proposed tasks, and log and send the data of the user interactions to a remote server. In this regard, a remote MongoDB database was used to store the set of events that occurred in the participants' browser, together with the corresponding timestamps. The set of events included the cursor location (X and Y coordinates) along its movement with a sampling frequency of 100Hz, in order to study different features of point and click trajectories. To identify invalid cursor trajectories and to delimit data for analysis, other events were also recorded, such as keystrokes, cursor clicks and page scrolls. Additionally, browser and experiment related events, such as page loads, or the start and end of tasks, were also gathered. To study other performance related features, each time a click event occurred we recorded the spatial information of the selected link (location, width and height) and of the other visible targets on the screen.

A separate Java application was implemented to parse interaction data gathered throughout the study and calculate a variety of measures from cursor trajectory that were later analysed with the RStudio statistical tool. This Java

TABLE 1. Information about study participants.

| | | | | Keyboard users group (KU) | | | | | | | | | | | | | Display | |
| | | | | Self-reported impairments | | | | | | | | | | | | | | |
ID	G	A	Health condition	Fa	Co	St	Mo	Gr	Ho	Tr	Sp	Se	Dir	Dis	Pointing device	Inches	Resolution
K1	F	46	Cerebral palsy	■			■	■		■			■	■	Keyboard + head wand	17	1366×768
K2	M	45	Cerebral palsy		■		■	■	■		■				Keyboard + head wand	26	1920×1080
K3	F	57	Glutaric aciduria t1				■	■	■		■				Keyboard	22	1360×768
K4	F	62	Glutaric aciduria t1	■	■	■		■	■		■	■	■		Keyboard	28	1920×1080

| | | | | Joystick and trackball users group (JU) | | | | | | | | | | | | | Display | |
| | | | | Self-reported impairments | | | | | | | | | | | | | | |
ID	G	A	Health condition	Fa	Co	St	Mo	Gr	Ho	Tr	Sp	Se	Dir	Dis	Pointing device	Inches	Resolution
J1	F	43	Cerebral palsy	■		■	■	■							Joystick	27	1536×864
J2	M	49	Cerebral palsy	■	■			■		■	■				Joystick	27	1536×864
J3	M	44	Cerebral palsy						■	■	■				Joystick	27	1920×1080
J4	M	48	Cerebral palsy	■	■			■	■	■					Trackball	23	1920×1080

Table includes details about each participant's gender (G), age (A), health condition, pointing device used, as well as the size of the monitor and resolution setup. Categories for self-reporting impairments in upper limbs [48] were: rapid fatigue (Fa), poor coordination (Co), low strength (St), low movements (Mo), difficulty gripping (Gr), difficulty holding (Ho), tremor (Tr), spasm (Sp), lack of sensation (Se), difficulty controlling direction (Dir), difficulty controlling distance (Dis).

application initially allowed us to organize a huge amount of data gathered from user tests; for instance, delimiting point and click trajectories from start to end point based on sequences of cursor movement events ended with a click event, or detecting erroneous point and click cursor trajectories if these included more than one click event.

C. TASKS AND MATERIALS

During the course of this longitudinal study the participants had to perform two different tasks on the browser installed on their computers: free navigation and target acquisition.

1) FREE NAVIGATION TASK

The participants were asked to use regularly (according to their habits) the web browser on their computers for personal and autonomous web navigation. The objective was for them to practice and get used to the virtual cursor, in order to allow us to explore usage and acceptance of both variants. Usage data generated during free navigation was remotely collected similarly to the target acquisition task, and included mainly cursor trajectories, data related to cursor clicks, and on-screen distribution of links on visited pages. The participants were able to deactivate the virtual cursor assistance and to use the original cursor at any time of web navigation. Activation/deactivation actions were registered. On the other hand, sensitive data about participants' privacy during their web navigation was not recorded by our data gathering tools (e.g., any typed text on the keyboard or information identifying the visited web pages).

2) TARGET ACQUISITION TASK

The participants were also asked to regularly repeat (but never more than once a day) the same target acquisition task until completing 15 sessions. This exercise consisted of a multidirectional point and click task with 12 targets arranged in a circular layout (Fig. 6) that was repeated for 3 target configurations (Fig. 7), and for both cursor variants tested by each participant (original cursor and corresponding virtual cursor). The participants had to complete a total of 72 trials per session. The order of both tested factors (cursor variant and target configuration) was counterbalanced between sessions, and the target sequence was randomized each time. Based on guidelines to assist problems with fine movements [52]–[54], target sizes were defined smaller than recommended (95 pixels width by 15 height) to test the benefit of the virtual cursors on more difficult cases. A constant radius of 250 pixels was used for the size of the circular layout, avoiding any horizontal or vertical scroll during this task. Before each trial, participants had to position the cursor over a home button located in the centre of the circular layout (Fig. 6). Upon selecting it, the home button disappeared and a new trial started in which participants had to select as fast as possible the displayed target labelled as "click here". After completing each trial, the home button re-appeared along with the next target. The goal of this task was to record cursor trajectories on intentional movements of target acquisition, avoiding unintended movements that might occur during free navigation.

D. PROCEDURE

During a first home visit each participant was briefed on the purpose and details of the experiment and then signed a consent form before beginning the longitudinal study. Information on demographics and about the computing equipment of each participant was collected through a preliminary interview. Next, we installed the browser and both add-ons on the personal computer of each participant so they could perform the experimental tasks autonomously throughout the longitudinal study. Participants were then taught to use the virtual cursor (Fig. 4), and to perform the proposed tasks without supervision from an experimenter. All participants completed a first supervised session of the target acquisition
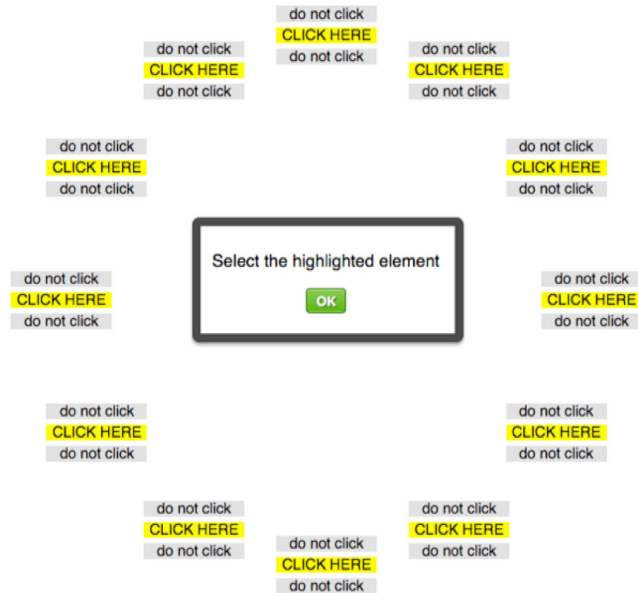
FIGURE 6. Circular layout of the target acquisition task showing all 12 targets at once for a particular distractor configuration, and with the home button in the center as the starting point for each trial. During the test only the current target was displayed to participants, the other 11 remained hidden.
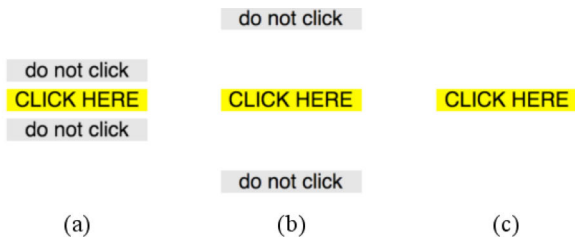

FIGURE 7. The three target configurations tested on the target acquisition task correspond to: a) configuration 1 with distractors 5 pixels away from target, b) configuration 2 with distractors 40 pixels away, and c) configuration 3 without any distractor near the target link.

task while we recorded their interactions with the pointing device using a video camera located behind them. To conclude this first home visit, the participants were invited to respond to a usability questionnaire to rate the virtual cursor just tested. Thereafter, participants were asked to use the installed browser autonomously for free navigation and to regularly perform the unsupervised target acquisition task.

Once participants had completed the target acquisition task fourteen times and enough data had been collected from the free navigation task, we visited them again to conclude the longitudinal study. Before that, participants had to complete the last supervised session of the target acquisition task (also recorded on video), followed by the same usability questionnaire that they had answered during the first visit, in order to compare both responses. After concluding the study, each participant was rewarded with a voucher worth 200 €in appreciation for their collaboration in the study.

E. MEASURES

Two different methods were used to compare the two virtual cursors with the original cursor. Firstly, participants filled in the same questionnaire both at the beginning and end of the longitudinal study to measure their satisfaction with the virtual cursor tested. We used the System Usability Scale (SUS) questionnaire [55] for this purpose, which includes 10 items to be rated on a 5-point Likert scale (from strongly agree to strongly disagree). Secondly, seven cursor path evaluation measurements described in the literature [10], [12], [56] were used to study the performance of participants with the cursor variants tested on target acquisition tasks. Although Fitts's law [57], as described by MacKenzie [58], has been widely used to study target acquisition in GUIs, we did not apply this paradigm in our evaluation as there is evidence against the suitability of Fitts's law to model pointing and clicking movements of people with MIs [59]. Furthermore, cursor trajectories of keyboard-only users do not follow the ballistic movement supposed by Fitts's law.

1) MOVEMENT TIME (MT)
The time interval from clicking the home button and until the target link is selected (Fig. 6). The MT corresponds to the total time needed to complete a trial, and was calculated based on the timestamps of the recorded events.

2) POINTING TIME (PT)
The time interval from when the cursor starts moving until it finally stops before the target link is selected (i.e., a click event occurred). The PT corresponds to the time needed to move the on-screen cursor to complete a trial. The PT is a portion of the total MT, and was also calculated based on the timestamps of the recorded events.

3) CLICKING TIME (CT)
The time interval from when the cursor finally stops moving until the target link is selected. The CT corresponds to the time needed to perform the click to complete a trial. The CT is a portion of the total MT, and was also calculated based on the timestamps of the recorded events.

4) DISTANCE TRAVELLED (DT)
The total distance traversed (in pixels) by the on-screen cursor along the pointing trajectory. The DT was computed for each trial as the sum of Euclidian distances from each point to the next point. The distance between two consecutive points (X_1, Y_1) and (X_2, Y_2) is given by:

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \qquad (1)$$

5) CURVATURE INDEX (CI)
The curvature index is the ratio of the DT to the straight-line distance between the starting and ending points of cursor trajectory. A value of one indicates the cursor has followed a straight line to the target, while larger values show increasing deviations. The CI was calculated based on the computed distance travelled for each trial and the corresponding distance between the home position and the target location.

6) NUMBER OF PAUSES (NP)

The times the cursor stops along the pointing trajectory to a target. The number of pauses indicates the number of trajectory corrections made by the user in order to select a target. Low values indicate fewer corrections and therefore fewer problems on the pointing trajectory, while high values means that the user has had more difficulties to reach a target. The NP was calculated based on the time interval between consecutive cursor motion events. According to interaction data gathered, time intervals equal to, or greater than, 100 milliseconds were considered as pauses.

7) TARGET RE-ENTRY (TR)

A TR occurs when the pointer enters the target region, then leaves, and then it enters again. A result of zero indicates perfect accuracy on target acquisition, while growing values mean increasing accuracy issues. For both virtual cursors, the TR was calculated considering as the target region the extended area from where selection from distance was possible.

V. RESULTS

The following subsections present results from qualitative and quantitative analyses about acceptance and performance achieved with the cursors tested.

A. FREE NAVIGATION TASK

Various measures were calculated from the interaction data collected in order to understand the browsing activity of each participant during the free navigation task. Table 2 shows results from each participant after filtering inactivity periods during web browsing of over 15 minutes without any user interaction. Some measures, such as the total number of hours (TH), number of sessions (NS), or total number of pages visited (TPV), reveal disparate results among participants. Despite this, all the participants were able to navigate on their own and repeatedly with the experimental browser throughout the study, as well as to use the corresponding virtual cursor extensively as shown by the PVtr values (Table 2).

B. TARGET ACQUISITION TASK

This section presents the results of the quantitative analysis of cursor trajectories to compare each of the virtual cursors with the original cursor. First, we describe how interaction data was filtered for subsequent statistical analysis.

1) DATA CLEANING AND USE OF VIRTUAL CURSORS

Each of the 8 participants repeated the same target acquisition task 15 times, which included 72 trials (half with each cursor variant tested), resulting in a total of 8640 trials (1080 trials by each participant). Interaction data gathered from participants was filtered before statistical analysis by removing invalid trials. Excluded trials were those corresponding to erroneous point and click interactions (i.e., any sequence of events different from a set of cursor movements followed by a target

TABLE 2. Browsing habits of each participant on free navigation task.

KU group (Cross & original cursors)						
	Participants					
Measure.	K1	K2	K3	K4	Distrib.	Mean	SD
TH	7	17.4	29.5	5.3		14.8	9.7
NS	55	90	70	30		61.3	21.9
ASDm	7.6	11.6	25.3	10.7		13.8	6.8
APDs	95.7	44	125.2	103.1		92	29.8
TPV	262	1423	848	186		679.8	499.8
APS	4.8	15.8	12.1	6.2		9.7	4.5
ADPS	4.2	12.3	9.1	5.2		7.7	3.2
PVtr	93.7	99.4	99.4	96.2		97.2	2.4

JU group (Area & original cursors)						
	Participants					
Measure.	J1	J2	J3	J4	Distrib.	Mean	SD
TH	9.6	2.2	62.6	3.4		19.5	25.1
NS	29	20	69	23		35.3	19.8
ASDm	19.8	6.5	54.4	9		22.4	19.1
APDs	132.4	60.5	168.4	65.9		106.8	45.5
TPV	260	130	1338	188		479	498.1
APS	9	6.5	19.4	8.2		10.8	5.1
ADPS	7	5.3	11.7	6.1		7.5	2.5
PVtr	80.3	99.2	99.3	97.3		94	8

Measurements calculated for each participant include: total hours browsing the Web (TH), number of sessions accessing the browser (NS), average session duration in minutes (ASDm), average page duration in seconds (APDs), total number of pages visited (TPV), average number of pages visited per session (APS), average number of different pages visited per session (ADPS), and time percentage using the virtual cursor variant tested over the original cursor (PVtr).

selection), as well as outlier trials with a movement time two standard deviations or more away from the participant's mean. In this way, 532 trials out of 4320 (12.3%) were filtered for the KU group, and 326 trials (7.5%) for the JU group, which in total corresponds to 858 (9.9%) of all target acquisition trials. Table 3 shows the distribution of invalid trials by cursor variant and filtering category for each group of participants.

Both the tested virtual cursors enable link selection without needing to hover the pointer over targets. Table 4 shows the percentage of valid trials completed by clicking from outside the target for each cursor variant and target configuration, as well as for each participant. Only half of JU group participants (J3 and J4) leveraged the area cursor on more than 50 percent of the trials (depending on target configuration)

TABLE 3. Distribution of filtered trials from target acquisition task.

Keyboard users group (KU)

Category	Cursor	Filtered	Distrib.	Mean	SD
Erroneous	Original	236 (10.9%)		59	34.3
	Cross	213 (9.9%)		53.3	22.8
Outliers	Original	45 (2.1%)		11.3	2.7
	Cross	38 (1.8%)		9.5	5.7
Total filtered	Original	281 (13%)		70.3	34.9
	Cross	251 (11.6%)		62.8	27.7

Joystick & trackball users group (JU)

Category	Cursor	Filtered	Distrib.	Mean	SD
Erroneous	Original	119 (5.5%)		29.8	38.7
	Area	73 (3.4%)		18.3	20.5
Outliers	Original	72 (3.3%)		18	5.2
	Area	62 (2.9%)		15.5	1.5
Total filtered	Original	191 (8.8%)		47.8	33.5
	Area	135 (6.3%)		33.8	19.9

TABLE 4. Percentages of links selected from outside the target.

Cross cursor – KU group

| Conf. | Participants | | | | Distrib. | Mean | SD |
	K1	K2	K3	K4			
1	143 (100%)	168 (100%)	152 (100%)	167 (100%)		100	0
2	143 (100%)	162 (100%)	171 (100%)	169 (100%)		100	0
3	144 (100%)	158 (100%)	167 (100%)	165 (100%)		100	0
Ov	430 (100%)	488 (100%)	490 (100%)	501 (100%)		100	0

Area cursor – JU group

| Conf. | Participants | | | | Distrib. | Mean | SD |
	J1	J2	J3	J4			
1	53 (31%)	32 (21%)	41 (25%)	61 (36%)		28.3	5.7
2	76 (43%)	68 (43%)	76 (45%)	121 (70%)		50.3	11.4
3	74 (42%)	64 (40%)	100 (58%)	151 (85%)		56.3	18
Ov	203 (39%)	164 (35%)	217 (43%)	333 (64%)		45.3	11.2

Table shows the distribution of results between the participants and the three target configurations tested (Fig. 7), as well as for the overall results of all configurations of the target acquisition task (Ov).

by clicking outside the target. Nonetheless, all JU group participants increased this ratio with the less restrictive target configurations (2 and 3). On the other hand, all participants
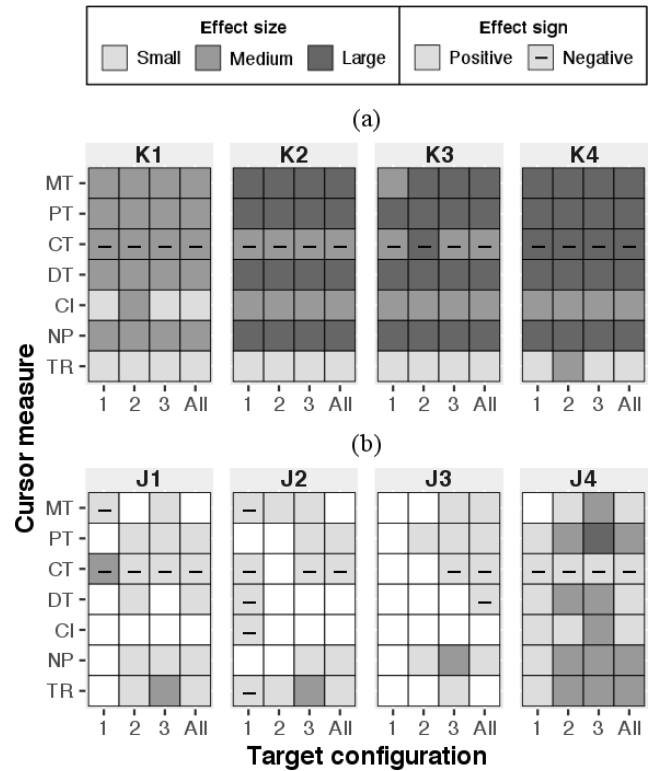

FIGURE 8. Summary of results from significance tests, showing on a tiled heatmap per participant the existence of significant differences between the original cursor and a) the cross cursor for KU group participants, or b) the area cursor for JU group participants. For each cursor measure and target configuration studied, a cell displays the effect size (small if r ≥ 0.1, medium if r ≥ 0.3, or large if r ≥ 0.5) and the effect sign, if significant differences existed between cursors. A blank cell means no significance was found.

from the KU group leveraged the cross cursor on every valid trial by tapping the corresponding shortcut key for target selection from distance.

2) CURSOR MEASURES

To compare the participants' performance with the different cursors (original cursor and cross or circular cursor respectively by KU group or JU group participants) we performed a quantitative analyse of cursor trajectories on the target acquisition task. A Wilcoxon signed-rank test was used for each cursor measurement, each target configuration (as well as for all configurations together) and each participant, to find out if significant differences existed between the tested cursors. Fig. 8 summarizes the results of the 224 statistical tests carried out ($7 \times 4 \times 8$), showing by means of tiled heatmaps the existence of significant differences between cursors and the effect sizes in such cases. Positive effect sizes in Fig. 8 correspond to the virtual cursor (cross or circular cursor for the KU group or the JU group respectively) improving the performance of the original cursor, whereas negative values represent the opposite.

The 4 participants from the KU group (K1 to K4) found significant differences between the cross and the original

cursor for all cursor measurements and target configurations (Fig. 8a). The cross cursor improved significantly the performance of each KU group participant for all cursor measurements, except for the clicking time (CT). Measurements for the movement time (MT), pointing time (PT), distance travelled (DT) and number of pauses (NP) reflected the highest effect sizes for every KU group participant, followed by the curvature index (CI) and target re-entry (TR). Concerning MT, PT, DT and NP, results from K2, K3 and K4 (Fig. 8a) showed consistently large effect sizes (0.50 to 0.57), except for MT (configuration 1) from K3 with a medium effect size (W = 8594, Z = 8.7938, p < 0.01, r = 0.46). Results from K1 for MT, PT, DT and NP showed consistently medium effect sizes (0.39 to 0.48). Regarding CI, results from K2, K3 and K4 corresponded to medium effect sizes (0.39 to 0.47), whereas K1 obtained small effect sizes (0.28 to 0.29) except for configuration 2 with a medium effect size (W = 1967, Z = 5.8455, p < 0.01, r = 0.31). Regarding TR, all participants from the KU group consistently obtained small effect sizes (0.11 to 0.29), except for K4 who obtained a medium effect size on configuration 2 (W = 1061, Z = 6.483, p < 0.01, r = 0.34). On the other hand, the CT worsened significantly with the cross cursor in comparison with the original cursor for all participants from the KU group. Results from K4 for CT showed consistently large effect sizes (−0.54 to −0.56), whereas participants K1, K2 and K3 obtained medium effect sizes (−0.35 to −0.49) except for K3 who obtained a large effect size on configuration 2 (W = 531, Z = −9.5826, p < 0.01, r = −0.51). In short, all participants from the KU group improved significantly on point and click tasks with the cross cursor on six of the seven measures studied, achieving similar results for each target configuration tested (Fig. 8a).

On the other hand, we found significant differences between the area cursor and the original cursor for all the measures studied, although results varied among JU group participants (J1 to J4) and the target configurations being tested (Fig. 8b). J4 obtained the most noteworthy benefits with the area cursor, achieving significant differences for all combinations studied (except for configuration 1 of MT), as well as the highest effect sizes. J1 obtained the second best results of the JU group with the area cursor compared to the original cursor, followed by J2 and J3 who obtained slightly less significant differences between cursor variants tested, as well as shorter effect sizes. Despite these differences, all JU group participants achieved the best results with the area cursor for measurements for MT, PT, NP and TR, on target configuration 3. Additionally, the highest effect sizes in favour of the area cursor corresponded to target configuration 3 and cursor measurement TR for J1 (W = 1655, Z = 5.9894, p < 0.01, r = 0.32) and J2 (W = 1870, Z = 5.7277, p < 0.01, r = 0.3), NP for J3 (W = 531, Z = 9.5826, p < 0.01, r = 0.33), and PT for J4 (W = 13676, Z = 9.7518, p < 0.01, r = 0.51). However, for all JU group participants the CT worsened significantly with the area cursor in comparison with the original cursor 9 out of 12 times. Results for CT showed small effect sizes for all participants (−0.1 to −0.27), except for J1
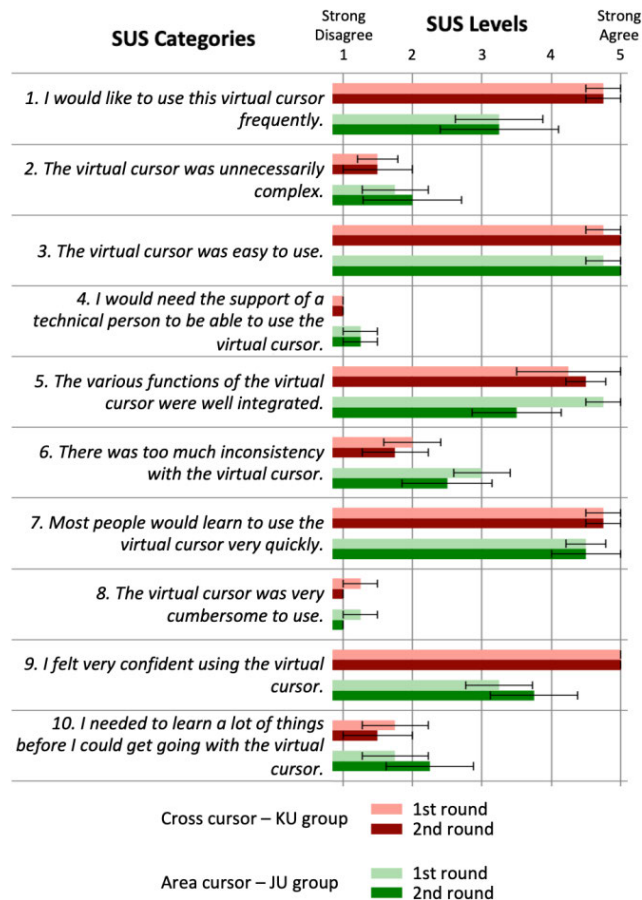

FIGURE 9. Average ratings by user group and round of questionnaire for the virtual cursor tested. Error bars represent ±1 standard error (SE).

who obtained a medium effect size on configuration 1 (W = 2507, Z = −6.7005, p < 0.01, r = −0.35). In summary, participants achieved the best results with the area cursor on less restrictive target configurations. Participant J4, using a trackball, obtained the greatest benefits from the JU group with the virtual cursor.

C. USABILITY QUESTIONNAIRE

Participants from both groups completed the SUS usability questionnaire twice, at different stages of the study, in order to gather their subjective assessments about the virtual cursor tested. Each participant responded to the 10 categories of the questionnaire, first at the beginning of the study after the training and first session of the target acquisition task, and second at the end after the last session of the target acquisition task. On average, both virtual cursors were positively rated for all categories of the SUS questionnaire, except the area cursor, which obtained a medium score of 3 points on the sixth item at the beginning of the study. In general, the cross cursor obtained better average scores than the area cursor, as well as less variability between subjects' responses. Fig. 9 includes bar graphs for each category of the SUS questionnaire, showing the distribution of responses by group of participants and questionnaire round.

The cross cursor got the worst results for categories 5, 6 and 10 of the questionnaire. Two participants from the KU group (K1 and K2) stated that they were confused at first about how to leverage the virtual cursor for link selection, and that they needed to practice to get used to it. Participant K3 reported that she visited a web site where she could not use the cross cursor for link selection, as the page contained a text bar that was continuously listening for the keyboard. After prolonged use of this virtual cursor, scores for categories 5, 6 and 10 tended to improve on the second round of the questionnaire. For the rest of categories, the cross cursor obtained very positive assessments from the beginning of the study.

The area cursor got the worst results for categories 1, 5, 6, and 9 of the questionnaire. J3, who made extensive use of the virtual cursor, stated that when there were a large number of links on the screen, visual cues about these could be tiring for his eyesight, and suggested highlighting only the target within reach. Two participants (J1 and J2) stated that sometimes the area cursor seemed to slow the web browser down, although this may have been due to using a less powerful computer. There were also opposing assessments, while J4 found the area cursor very useful for him and thought he would like to use it frequently, participant J3 said he did not need it for assisting his web browsing. After extensive use of the area cursor, some assessments improved (such as items 6 and 9) while others worsened (such as items 5 and 10).

VI. DISCUSSION

Both virtual cursors tested in this longitudinal study proved to be beneficial for the participants according to the results from the quantitative and qualitative analyses carried out. The cross cursor and the area cursor improved performance and satisfaction of the participants of the keyboard users group (KU), and the joystick and trackball users group (JU) respectively, albeit to a different extent. The discussion of these results aspires to provide clues for further research on link selection assistance.

A. THE CROSS CURSOR

The quantitative results indicated that the cross cursor was extensively used by the KU group during the free navigation task (active on average 97.2% of the time, SD = 2.4), resulting in an average of 61.3 sessions accessing the Web per participant (SD = 21.9). The amount of invalid trials on the target acquisition task was slightly reduced by KU group participants when using the cross cursor (Table 3), showing that this virtual cursor was not more error prone on link selection than the original cursor. Results from statistical tests showed that all participants from the KU group significantly improved link selection with the cross cursor in comparison with the original cursor according to 6 out of the 7 performance parameters studied (Fig. 8a). The cross cursor outperformed the original cursor in the following parameters: movement time (MT), pointing time (PT), distance travelled (DT), curvature index (CI), number of pauses (NP) and target re-entry (TR), which confirmed cross cursor benefits

on pointing trajectories and on accuracy to reach targets. However, the clicking time (CT) significantly worsened with the cross cursor in comparison with the original cursor for any member of the KU group. This was due to the fact that, in order to leverage the cross cursor, the user had to identify on the screen the letter assigned to the reachable target and then type it on the keyboard. By contrast, for clicking links with the original cursor, keyboard-only users always stroke the same key (Fig. 3a). Despite this worse performance on CT with the cross cursor, all KU group participants significantly improved total MT (which includes CT) using the cross cursor in comparison with the original cursor. Considering that keyboard-only users can type some keys more easily than others depending on their physical condition, it should be studied how to map the shortcuts to links in order to optimize CT. For instance, it would be beneficial to identify the most efficient shortcuts for each user considering their keyboard use. Therefore, the easiest shortcuts may be assigned to the most relevant links within visited web pages.

The members of the KU group achieved similar statistical results regardless of the target configuration being tested (effect sizes in Fig. 8a). According to these results, the performance with the cross cursor of the keyboard users was not affected by how far apart links are presented from each other within a web page.

Qualitatively, similar and highly positive opinions about the usability of the cross cursor were given by KU group participants (Fig. 9). The average SUS score from the KU group for the cross cursor was 90 points out of 100 (SD = 10.6) at the beginning of the study, and 93.1 points (SD = 9.4) at the end, showing a small improvement after extensive use. Despite all KU group participants having been trained to use the cross cursor, several declared that it was confusing at first and that they needed to get used to this new assistance to be able to take better advantage of it. Progression of the KU group throughput (TP) during the course of the 15 target acquisition task sessions showed an improvement on performance with the cross cursor when compared with the original cursor (Fig. 10a). The corresponding linear functions of each cursor variant reveal that the KU group improved their TP almost 10 times more with the cross cursor than with the original cursor. More training with advanced guidance on key aspects of this new virtual cursor functioning may reduce the learning period.

B. THE AREA CURSOR

Quantitative results showed that the area cursor was extensively used by the JU group during the free navigation task (active on average 94% of the time, SD = 8). Each participant accessed the Web for an average of 35.3 sessions (SD = 19.8) throughout the study. The amount of invalid trials on the target acquisition task was slightly reduced by JU group participants when using the area cursor (Table 3), showing that this virtual cursor was not more error prone on link selection than the original cursor. The results from the statistical tests showed that the JU group participants significantly improved
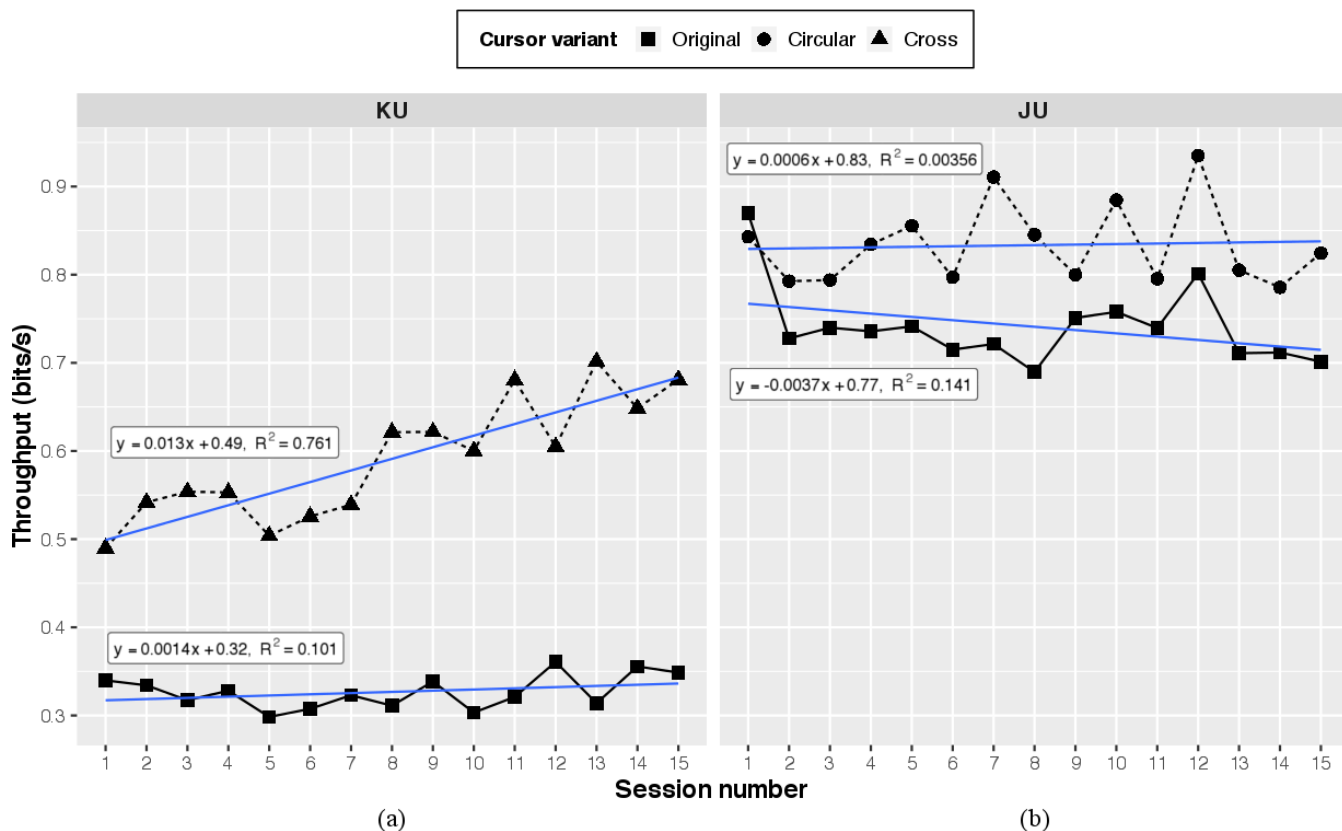
FIGURE 10. Relationship between the average throughput (TP) of each user group with each cursor variant, and the target acquisition task session (from 1 to 15): a) KU group with the original and cross cursor, and b) JU group with the original and area cursor. The TP was calculated by dividing the index of difficulty (bits) of trials as defined by [60], between the mean MT. Graphs also include linear regression lines and corresponding prediction equations.

link selection with the area cursor in comparison with the original cursor according to 6 of the 7 performance measurements studied, although there were variations between participants and target configurations tested (Fig. 8b). Statistical results for the MT, PT, NP and TR registered significant differences in favour of the area cursor for all JU group participants, confirming its benefits on pointing trajectories and on accuracy for reaching targets. By contrast, two JU group participants (J1 and J4) significantly improved with the area cursor in comparison with the original cursor on the DT, whereas only one (J4) on the CI. On the other hand, their CT significantly worsened with the area cursor, partly due to the implementation of this virtual cursor. Each time the pointer stopped moving, the area cursor needed a few milliseconds to calculate and highlight the closest target. Although this issue was not mentioned by participants, an improved implementation of the area cursor should reduce this response time. In addition, results from statistical tests (Fig. 8b) showed that for most cursor measurements, performance of JU group participants with the area cursor improved on less restrictive target configurations (Fig. 7b and Fig. 7c). On the other hand, the benefits of the area cursor were attenuated, or even disappeared for some participants, on the most restrictive target configuration (Fig. 7a).

According to these results and to the opinions of some participants, who argued that the area cursor added too

much information to Web GUIs, this virtual cursor may be improved by adapting its assistance dynamically. Assistance may be automatically deactivated when moving over links that are very close to each other. Other cursor enhancements relying on magnification approaches should be tested in those cases [48]. However, the assistance may be activated again when moving over links that are further apart. Introducing an adaptive bubble cursor approach [61] that dynamically increases and decreases the selection area according to cursor proximity to the surrounding links may also be useful. In addition to these enhancements, a different approach can be adopted: that of adapting the virtual cursor to the type of web page being visited, its structure, or the areas detected within its layout (navigation bar, banner, content, etc.). In order to avoid the loss of performance from the standard area cursor, this could be combined with a transcoding system for adapting web content on the fly. For instance, a transcoding system that automatically adapts web pages, such as the one presented by Valencia *et al.* [62], could be used to increase the distance between close links.

Qualitatively, the usability of the area cursor was evaluated positively by participants from the JU group (Fig. 9), although on average it received lower scores than the cross cursor. Average SUS score from the JU group for the area cursor was 78.8 points out of 100 (SD = 4.3) at the beginning of the study, and 77.5 points (SD = 8.4) at the end, showing

similar scores but a higher variability after prolonged used. Several participants from the JU group highlighted difficulties to leverage the area cursor when the links were too close together, as indicated by the answers to items 2, 5, 6 and 9 (Fig. 9). Although the functioning of the area cursor was assessed by participants as being easy to understand from the beginning, no improvement was appreciated on the TP progression over the course of the 15 sessions of the target acquisition task (Fig. 10b). Despite the fact that evolution of the TP shows a strong variation across sessions for both cursor variants being tested, participants of the JU group achieved, on average, better performance with the area cursor than with the original cursor. Performance improvements should be studied by testing the different enhancements proposed in the previous paragraph for selection of closely spaced links with the area cursor.

VII. CONCLUSIONS

The longitudinal study we have presented here aims to explore the long-term benefits of two virtual cursors for assisting link selection on the Web to two different groups of people with MIs. Two groups of experienced users with different alternative pointing devices participated from their home on this remote 6-week unsupervised study to evaluate each virtual cursor: the novel cross cursor by keyboard-only users, and a standard area cursor by joystick and trackball users.

Interaction data and subjective assessments were collected over the six weeks. Generally, participants assessed both virtual cursors positively. Although they were able to deactivate the assistance during web browsing, participants extensively used both virtual cursors (more than 80% of the total time).

Quantitative results showed that the cross and area cursors improved the performance of both groups of participants compared to the original cursor. Except for the clicking time, the other six performance measurements studied were significantly improved with both virtual cursors. The group of joystick and trackball users improved their performance with the area cursor in comparison with the original cursor on the less restrictive target configurations (i.e., when the target link was further away from other links or distractors). On the other hand, the performance of keyboard-only participants did not worsen with the cross cursor compared to the original cursor on closely spaced links and was similar for all three target configurations tested.

Several improvements were proposed in order to reduce the clicking time both with the cross cursor and the area cursor. Other enhancements were also proposed to improve the performance of the standard area cursor on web environments with closely spaced links.

ACKNOWLEDGMENTS

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