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Evaluation of two virtual cursors for assisting web access to people with motor impairments

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ABSTRACT

People with motor impairments (MI) may face accessibility barriers when using computers due to their health conditions and therefore need to use alternative devices to a standard mouse for pointing and clicking in graphical user interfaces (GUI). In this study with users of different pointing devices, we evaluate 2 virtual cursors (the novel cross cursor and the standard area cursor) implemented for assisting link selection on the Web by reducing respectively cursor displacement and the precision required. Both cursor adaptations were developed for this work based on previous research, and have been compared with the original unassisted cursor in a web-based study with fifteen regular computer users applying their usual pointing device. Nine participants with MIs participated, including 4 using keyboards as an alternative pointing device, 4 joystick users and 1 trackball user. Six participants without MIs also participated in the study applying a standard mouse to complete the same experimental tasks. User interactions with the pointing device, as well as subjective assessments about the usability of the cursor variants tested were gathered from study participants. An in-depth analysis of point and click trajectories showed that virtual cursors improved the effectiveness and efficiency of most participants with MIs in link selection. Subjective assessments about cursor variants tested showed that a majority of participants with MIs generally preferred one of either the two virtual cursors to the original one for web navigation.

1. Introduction

People with motor impairments (MI) may have problems using standard input devices to access computers (e.g., mouse) due to lack of dexterity in their upper limbs (Trewin and Pain, 1999), and therefore need to use assistive technologies (AT). MIs can hinder user interactions with computers in different ways (Sears et al., 2008), including, among others: poor coordination, slow movements, low strength, tremor, spam, rapid fatigue, or difficulty controlling direction or distance. Some diseases (WHO, 2001) resulting in MIs hindering the use of computers are: cerebral palsy, spinal cord injury, multiple sclerosis, muscular dystrophy, Parkinson's disease, arthritis or missing limbs and digits. In order to facilitate access to computers to this heterogeneous group of people, many different ATs have been developed (Cook and Polgar, 2014), such as, for example, mouse alternatives enabling direct interaction in graphical user interfaces (GUI). In a similar vein, some ATs that allow people with MIs to interact with an on-screen cursor are: specific alternative pointing devices such as a joystick or trackball, or software applications such as mouse keys to use the numeric keypad on a keyboard as a pointing device.

Despite these ATs people with MIs still find challenges when interacting with standard GUIs, such as, for example, selecting links on the Web (Trewin, 2008), so further research is needed to continue enhancing computer access for all of these users. Many studies have investigated difficulties faced by people with MIs when pointing and clicking targets on GUIs (Almanji et al., 2014; Hwang et al., 2004; Keates et al., 2002; Payne et al., 2017; Pérez et al., 2015; Valencia et al., 2017). Also other works have proposed new selection methods with on-screen cursor to assist point and click interactions on GUIs for people with MIs (Grossman and Balakrishnan, 2005; Harada et al., 2006; Hwang et al., 2003; Mott and Wobbrock, 2014; Payne et al., 2016; Salivia and Hourcade, 2013; Trewin et al., 2006; Wobbrock and Gajos, 2008). Nevertheless, these works mainly carry out tests with users of similar pointing devices, on repetitive tapping tasks within closed experimental environments, and focused on studying user performance. To improve both performance and experience of people with MIs accessing GUIs with any AT, new cursor enhancements have to be studied, with different users of alternative pointing devices, and on tasks recreating activities from their everyday computer use.

Based on previous work (Pérez et al., 2014) about web navigation strategies of users with MIs, we developed two virtual cursors as browser add-ons for assisting point and click interactions on the Web to

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two groups of users of alternative pointing devices. The novel cross cursor aimed at keyboard users to reduce cursor displacement when pointing, and the standard area cursor aimed at joystick and trackball users to reduce the accuracy needed to select links. The objective of this work was to study empirically the suitability of both virtual cursors for assisting web browsing with users of different pointing devices, by means of performance and satisfaction measures. For this purpose a web-based test was conducted with people with MIs users of the aforementioned alternative devices, as well as with mouse users without MIs in order to compare the performance and acceptance of cursors tested by the different groups of users. Several measurements from literature were calculated from point and click trajectories recorded during user tests (MacKenzie et al., 2001; Keates et al., 2002; Hwang et al., 2004) to compare performance achieved by participants with each cursor variant. We studied the usability of each cursor variant tested from subjective assessments of study participants, gathered by means of questionnaires based on reference works (Brooke, 1996; Hart and Staveland, 1988). Study findings were promising in terms of performance and satisfaction achieved by participants with MIs, and showed that users of alternative pointing devices can clearly benefit from point and click facilitators for accessing the Web. The study results also suggested that the pointing device used by the user is a good indicator in order to provide a better cursor assistance for people with MIs.

The rest of the paper is composed of the following six sections. Related work about enhanced cursors for assisting point and click interactions for people with MIs are described in Section 2. The two virtual cursors implemented to assist link selection on the Web for people with MIs using alternative pointing devices are presented in Section 3. Experimental evaluation methodology is explained in Section 4. Results obtained from this research are detailed in Section 5. The discussion about results of the study is included in Section 6. Conclusions about this research and future work are presented in Section 7.

2. Related work

Much research has been done into facilitating pointing and clicking in GUIs even though little of it has been specifically focused on assisting people with MIs on the Web. The following works proposed some renowned cursor enhancements to assist pointing and clicking 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 served to define the basis of our research.

The steady clicks assistance (Trewin et al., 2006) suppresses accidental clicks and slipping when clicking by freezing the cursor during mouse clicks, preventing overlapping button presses and cancelling clicks made while the mouse is moving at a high speed. The evaluation showed that this option improves time performance and enables users with MIs to select targets using fewer attempts; moreover, participants expressed their preference for this assistance (9 out of 11) over the unassisted condition. This alternative aims to assist the clicking task for people with low dexterity in their upper limbs, but its usefulness for keyboard-only users is not so obvious, since these are more affected by distance to target than accuracy.

The angle mouse (Wobbrock et al., 2009) is a pointing facilitation method that attempts to improve target acquisition by adjusting the mouse control-display gain based on the deviation angles of the cursor path sampled during movement. Thus, unlike most cursor enhancements, this technique (like the previous one) is based solely on the user's behaviour and requires no knowledge of targets on the GUI. Study results proved that this alternative improved pointing performance for users with MIs while remaining unobtrusive for people without impairments. However, all participants from the study (both with MIs and without MIs) were using the same standard mouse to complete experimental tasks and no alternative input device was tested.

Wobbrock and Gajos (2008) claimed that the difficulties faced by people with MIs could be alleviated in a different target acquisition paradigm called goal crossing where users do not aim at a restricted area, but instead pass over a target line to select it. Empirical results indicated a preference for goal crossing among people with MIs, although error rates were higher with this alternative. Authors also introduced some design principles for this new target acquisition paradigm, but these are not usable on standard web interfaces.

Hwang et al. (2003) studied the performance of users with and without MIs in a point and click task with force feedback applied to targets modelled as virtual gravity wells. Their results showed the greatest improvements for the users with the most severe impairments, even when multiple on-screen targets were haptically enabled. This technique looks promising for complex GUIs with numerous targets such as the Web, although the study did not include any subjective perception from participants about tested enhancements, or test different alternative pointing devices.

Worden et al. (1997) studied the effectiveness of two interaction techniques: the area cursor and the sticky icons, for improving the performance of older adults (with declined motor abilities) in basic selection tasks. The area cursor, successfully tested before with people without MIs (Kabbash and Buxton, 1995), is a cursor with a larger activation area than normal. 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 improved pointing time, especially the area cursor when the target icon was not in close proximity to another icon and for smaller target sizes. Results also showed that neither technique impeded performance in problematic cases (e.g., differentiation between closely spaced targets). Other works have studied enhancements for the area cursor, by dynamically resizing the cursor's activation area (Grossman and Balakrishnan, 2005), or with different combinations of visual and motor magnification or goal crossing (Findlater et al., 2010; Mott and Wobbrock, 2014; Payne et al., 2016). Results from these works generally revealed improvements in performance, although they were mainly based on users without MIs, the pointing device used was generally the mouse, or participants sometimes did not prefer the proposed methods.

Felzer et al. (2016) compared two different methods for mouse emulation with a numeric keypad called DualPad. The first method was called CKM and allows moving the mouse pointer in cardinal directions and clicking similarly as with the mouse keys application. The second method was the DualMouse, and 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 a higher throughput with the CKM method than with the DualMouse. Surprisingly, no cursor enhancement has been investigated to assist pointing and clicking interactions of keyboard-only users applying the mouse keys application included in every major operative system. There are applications such as VimVixen[1] (a Mozilla Firefox add-on) that enables web browsing by using only the keyboard. These applications label every link of a web page with shortcuts, so that a user can select any link keystroking the corresponding sequence of letters from his/her keyboard and without having to move the cursor pointer at all. The cross cursor that we developed for this study aims to reduce shortcuts to only one letter key each by combining cursor movements to label just those links at reach of this virtual cursor (Fig. 1 Right).

Pierson and Magee (2017) present a browser plug-in that implements a predictive link following algorithm for assisting link selection to people with MIs. Their algorithm analyses mouse movement and erroneous clicks before instructing the browser to follow a link.

[1] https://addons.mozilla.org/en-US/firefox/addon/vim-vixen

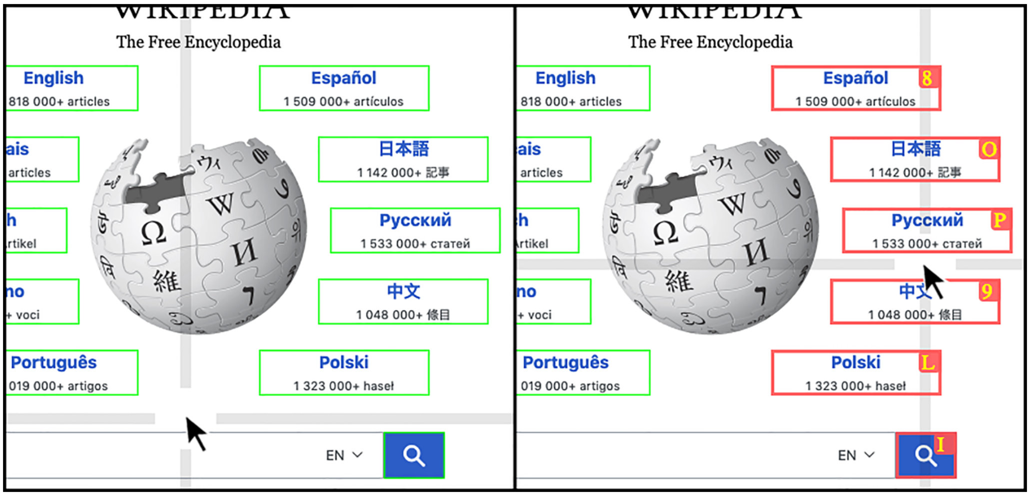

Fig. 1. (Left) The cross cursor without any link at reach, and (Right) with 6 links at reach via keyboard shortcuts after diagonally moving the cursor up to the right.

Experimental evaluations of their system with different pointing devices reported an improved performance with the proposed approach.

The Fitts' law paradigm has been widely applied to the comparison and optimization of pointing devices and interaction techniques as in Wobbrock and Gajos (2007). However, there are conflicting reports that differ on whether Fitts' law can be applied to pointing movements of people with motor impairments or not. While some works contribute with evidence in favour of the suitability of Fitts' law (Rao et al., 2000), others affirm just the opposite (Gump et al., 2002). Considering that pointing trajectories of keyboard user do not follow a ballistic movement supposed by Fitts' law, our evaluation was based on cursor measures as detailed in Section 4.

3. Virtual cursors

In previous works (Pérez et al., 2015, 2014; Valencia et al., 2015) concerning pointing and clicking behaviours of people with MIs, we observed that main difficulties faced by participants varied depending on the pointing device alternative used. Thus, users of keyboard as pointing device were more affected by the total distance to the link and by the pointing trajectory until reaching the target, whereas users of specific alternative pointing devices such as the joystick or trackball tended to have more problems near targets to stop the cursor over them. In order to study empirically if these web browsing issues faced by people with MIs can be alleviated by means of pointing and clicking assistances, we developed 2 virtual cursors as browser add-ons and tested them with real users on real web environments. Both virtual cursors, the novel cross cursor (Fig. 1) and the already existent area cursor (Fig. 2) were design to assist web browsing to people with MIs, by implementing different techniques to modify standard pointing and clicking. In the following 2 subsections we present both virtual cursors, how the new pointing and clicking assistances work, as well as some technical details.

3.1. The cross cursor

This virtual cursor aims to assist target acquisition on the Web by reducing cursor displacement required for pointing. This is achieved by combining cursor movement and providing single-letter shortcuts to every link at reach of the cross cursor (Fig. 1 Left and Right). Links at reach of this virtual cursor are those traversed by the cross cursor lines. The cross cursor continuously displays along its movement 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 reached by the cross cursor each time the virtual cursor stops motion, 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, having to approach them with the cursor pointer 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 users as alternative pointing device to use the numeric keypad as a mouse alternative (Fig. 3 left) by pressing the central '5' key for cursor clicking, and the surrounding number keys for moving it in vertical, horizontal and diagonal directions (Fig. 3 right).

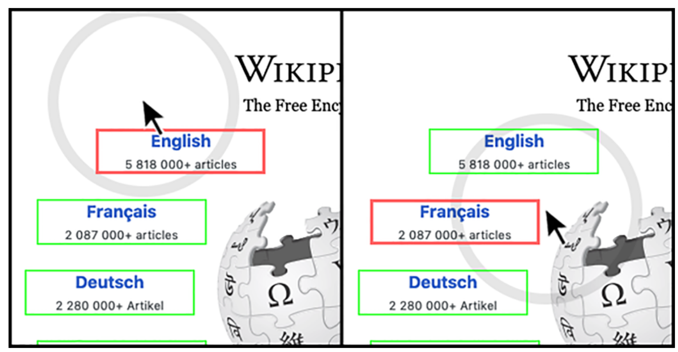

Fig. 2. (Left) The area cursor allows clicking a nearby link without needing to hover the cursor over it. Link at reach is highlighted in a different colour. (Right) If the activation area of this cursor reaches more than one link, the nearest one to the cursor pointer is highlighted and can be selected.

3.2. 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. The area cursor continuously displays as it moves a circle of fixed size that is always centred with its current position (Fig. 2) and which corresponds to its activation area. In this way, this virtual cursor enables the closest link within its activation area to be clicked (highlighted targets in red in Fig. 2) without needing to hover over it. We used fixed values for the visual appearance of the area

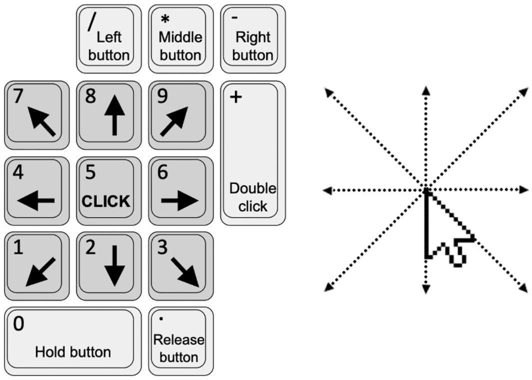

Fig. 3. (Left) Numeric keypad located on the right side of a keyboard highlighting the set of keys used by mouse keys for cursor pointing and clicking. (Right) Eight possible paths that cursor can travel from its current position when using mouse keys.

cursor (10 px width and 90% translucent grey colour) as well as for the activation area diameter (130 px).

Both virtual cursors were implemented using Scalable Vector Graphics (SVG) to add visual elements (lines, circles, rectangles and letters), along with JavaScript to handle users' interactions with the cursor and the web content. The add-on that implements each virtual cursor is in charge of parsing every visited web page to find all the links included. 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 with the virtual cursors as presented here.

4. Experiment method

In order to compare both virtual cursors (area and cross) with the original cursor, we carried out a web-based experiment with people with MIs and people without disabilities, applying their usual pointing device. For the purpose of analysing cursor movements on point and click interactions, two kinds of task were defined: searching tasks and target acquisition tasks. Cursor trajectories, as well as other related events were recorded during experimental sessions within an interaction log for later analysis. After participants completed experimental tasks, their subjective assessments were also gathered to measure the usability of each cursor variant tested. This study was approved by the Ethics Committee for Research Involving Human Beings from the University of the Basque Country.

4.1. Participants

A total of 15 participants took part in this study, 9 of which were people with MIs involving reduced mobility in their upper limbs. The other 6 participants were people without impairments, recruited as control subjects. All participants were regular computer users, accustomed to accessing the Web frequently, and were specifically chosen to participate in the study based on their usual input device alternative for mouse pointing in graphical user interfaces. In this way, the following 3 groups were defined:

- **KU group** with 4 keyboard users (3 females, mean = 49 years, SD = 7.8)
- **JU group** with 5 participants, 4 joystick users and 1 oversized trackball user (2 females, mean = 50.2 years, SD = 15.1)
- **MU group** with 6 mouse users (2 females, mean = 33.2 years, SD = 5.2)

All participants from the KU and JU groups were people with limited dexterity in their upper limbs that prevented them from using a standard mouse. All of them were experienced users with the pointing device alternative used during the experiment, and were mainly recruited from the Elkartu association of people with physical disabilities from our local area. Two participants from the KU group (KU1 and KU2) were able to push keyboard keys directly with their hand, while the other two (KU3 and KU4) needed a head wand. By contrast, participants from the MU group were people without disabilities and with over 7 years of experience using the mouse as their usual pointing device for computer access. Table 1 shows detailed information about the 15 participants of the study, grouped by the alternative pointing device used, including: each person's gender, age, regularity of use and years of experience with the corresponding pointing device, health condition (if applicable), and location where the experimental session was carried out (at their home, in a laboratory of the University of the Basque Country-UPV/EHU or on the premises of the Elkartu association).

4.2. Apparatus

All participants used the same equipment to complete the experiment, except for the pointing device. A Dell Precision M6700 laptop running a 64 bits version of the Windows 7 OS was used alongside an additional 24 in. widescreen LCD monitor (Dell model U2412MB) to

Table 1
Demographic data about study participants grouped by pointing device used.

Id	Gender	Age	Pointing device	Use	Exp.	Health condition	Location
Keyboard users group (KU)							
KU1	F	58	Keyboard	Daily	+7	Glutaric aciduria t1	Home
KU2	F	53	Keyboard	Daily	+7	Glutaric aciduria t1	Home
KU3	M	42	Keyboard + head wand	Daily	+7	Cerebral palsy	Home
KU4	F	43	Keyboard + head wand	Daily	1–3	Cerebral palsy	Home
Joystick & trackball users group (JU)							
JU1	M	45	Oversized trackball	Daily	+7	Cerebral palsy	Lab
JU2	M	42	Joystick	Daily	+7	Cerebral palsy	Home
JU3	M	46	Joystick	Daily	+7	Cerebral palsy	Lab
JU4	F	41	Joystick	Daily	+7	Cerebral palsy	Home
JU5	F	77	Joystick	Weekly	4–6	Spinal cord injury	Elkartu
Mouse users group (MU)							
MU1	F	30	Mouse	Daily	+7	–	Lab
MU2	F	33	Mouse	Daily	+7	–	Lab
MU3	M	30	Mouse	Daily	+7	–	Lab
MU4	M	28	Mouse	Daily	+7	–	Lab
MU5	M	36	Mouse	Daily	+7	–	Lab
MU6	M	42	Mouse	Daily	+7	–	Lab

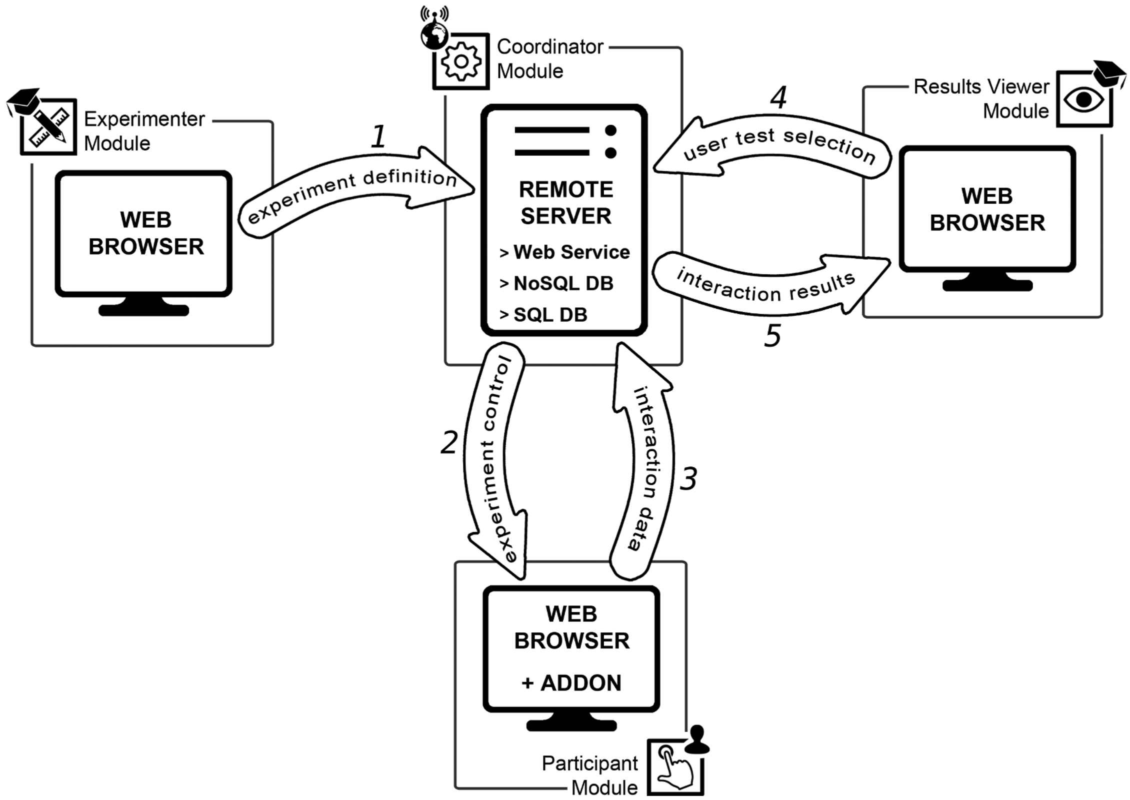

Fig. 4. The RemoTest platform general architecture and interactions between modules.

present the stimuli to participants. Participants from the KU and JU groups used their own personal input device alternative for mouse pointing while participants from the MU group used the same optical USB mouse (Dell model M-UVDEL1). Before starting the study, participants were encouraged to adjust the pointer motion options on the Windows control panel to fit their own preferences, and thus ensure their best performance during the experimental tasks.

The RemoTest platform (Arrue et al., 2018; Valencia et al., 2015) was used to specify and conduct the experimental sessions of this study. The architecture of the platform is based on a hybrid architecture model that includes some functionality in a client-side module and the other ones in some server-side modules. The platform is split into four modules: Experimenter Module (EXm), Participant Module (PAm), Coordinator Module (COm) and Results Viewer Module (RVm). Fig. 4 shows the general architecture and interactions between these modules.

Each module has specific functions and uses different technologies. The EXm module is responsible of assisting experimenters in the experiment definition process. The experiment definition is stored in a XML file based on the vocabulary of the specifically developed Experiment Specification Language. This file is the input for the COm module (Step 1 in Fig. 4). The COm module transforms the experiment specifications into personalized experimental sessions specified in XML format. These personalized sessions are transferred to the corresponding PAm modules (Step 2 in Fig. 4). The PAm module guides participants during the experimental sessions and gets the required user interaction data. This data is sent to the COm where it is stored for future analysis (Step 3 in Fig. 4). The RVm module organizes and presents the abundant interaction data gathered in an experiment, provided by the COm module (Step 4 and 5 in Fig. 4).

The experiment described in this paper was defined using functionalities of the EXm module of the RemoTest platform and an add-on was created for each participant with all the necessary data for presenting the experiment tasks to participants. This add-on is the PAm module of the platform, which was installed in the Mozilla Firefox web browser, used in the experimental sessions in conjunction with another add-on that implemented both of the virtual cursors. The user interaction data gathered during the experimental sessions was transmitted to the COm module and stored in a MongoDB database. This interaction data consisted of on-screen cursor trajectories with a sampling frequency of 100 Hz (X and Y cursor coordinates recorded each 10 ms approximately), as well as selected link (top, bottom, left and right coordinates) in order to later compare participants' performance with each cursor variant. Other user interactions with input devices (keystroke, click, page scroll, etc.) were also gathered, as well as browser and experiment events (page load, start and end of tasks, etc.) in order to identify valid cursor trajectories and delimit data for analysis. For this purpose, a separate Java application was implemented to parse interaction data recorded from participants and calculate a variety of measures for each trial, which were later analysed with the RStudio statistical tool.

4.3. Tasks and materials

Participants were asked to perform a set of tasks during the experimental session within two different websites: Discapnet (2015) and Gipuzkoa (2015). Discapnet (Fig. 5 left) is a website which provides information aimed at people with disabilities, organizations or relatives of people with disabilities. They provide news, information about the rights of people with disabilities, etc. Gipuzkoa (Fig. 5 right) is an institutional website of the Gipuzkoa provincial council with news relating to the council, institutional information about local governments, etc. A third website about touristic information of the Bidasoa local area (Bidasoa Turismo, 2015) was used for training purposes, so participants could learn how to use the virtual cursors being tested, as well as to inform them about the experimental tasks they were going to carry out next. All 3 websites claimed, within their accessibility sections, to conform to a certain level of the WCAG 1.0 guidelines (Discapnet to Level AA, Guipuzkoa and Bidasoa to the Level A).

Fig. 5. Home page of both websites that study participants had to navigate to complete experiment tasks: Discapnet (left) and Gipuzkoa (right).

Two types of tasks were defined to be performed with each cursor variant tested (original, area and cross):

- *Search tasks*: in which study participants had to navigate through both proposed websites searching for different content, starting each time from the home page of the corresponding site. All searches had a similar level of difficulty, with the objective content located at 3 levels from the home page. A total of 12 different search tasks were defined, 6 within Discapnet (2015) and 6 within Gipuzkoa (2015), each to be completed within a 3 min time limit. These 12 search tasks were distributed between the 3 cursors tested (2 searches from each website by cursor variant) counterbalancing the order between participants. The goal was twofold: firstly that participants practiced and became familiar with how to select links with cursor variants before the following tasks, and secondly to gather their subjective assessments after a natural usage of cursors. In addition, 3 more search tasks were defined within the Bidasoa Turismo (2015) website for training purposes, each of which had to be completed by participants with a cursor variant before carrying out the actual experimental tasks. During search tasks the current objective was displayed at the bottom of the browser continuously, so that participants did not forget what they were looking for (Fig. 6 bottom).
- *Target acquisition tasks*: in which study participants had to sequentially select highlighted links on the browser screen. In order to cover different approaching angles in each trial, chosen targets were evenly distributed between quadrants of imaginary Cartesian axes centred on the screen. In this way, a total of 48 targets were defined (half from each website) that had to be selected by participants with each tested cursor variant. Before each trial, participants had to position the cursor over a home button located in the centre of the screen (Fig. 7). Upon selecting it, the home button disappeared and a new trial started, in which participants had to select the highlighted link on the screen as fast as possible. After completing each trial, the home button re-appeared and next target was highlighted. The goal was to record cursor trajectories on intentional movements of target acquisition (avoiding unintended moves that might occur during search tasks) in order to compare performance achieved with each cursor variant. In addition, 5 more targets were defined within the Bidasoa Turismo (2015) website for training purposes, that participants had to select with every tested cursor variant before carrying out actual experimental tasks.

4.5. Procedure

First, participants were briefed on the purpose of the study and then signed a consent form before starting with the experimental session. Information on demographics and about expertise with the corresponding pointing device was collected through a brief pre-session interview. Prior to testing, experimental tasks and virtual cursors were introduced to participants through demonstration and practice during a training session of between 10–20 min (5–10 min in the case of participants without MIs). Participants had to complete 3 consecutive training blocks corresponding to the 3 cursor variants being tested, each one including a search task followed by 5 target acquisition tasks. The Bidasoa Turismo (2015) website was exclusively used for this purpose.

After concluding the training session, participants had to complete actual experimental tasks grouped in 3 consecutive blocks corresponding to each cursor variant tested (original, area and cross). Cursor blocks were presented in counterbalanced order to participants, and each included 4 search tasks followed by 48 target acquisition tasks,

Fig. 6. Browser status bar at the botom displaying enlarged text of the content to look for within Gipuzkoa website during a search task.

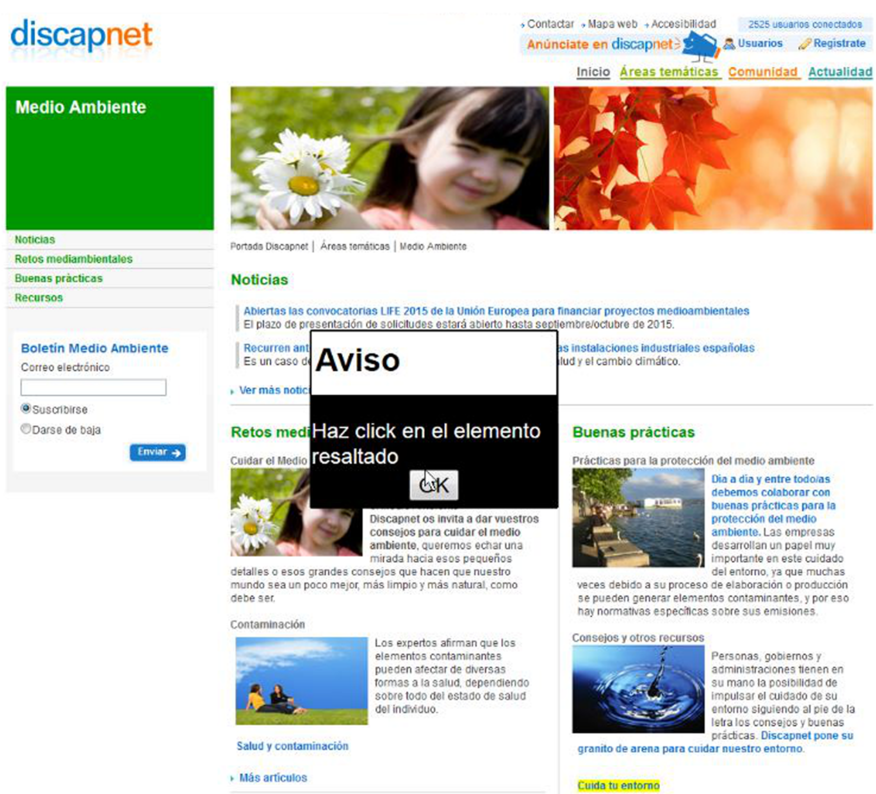

Fig. 7. Screen capture of a target acquisition trial, with cursor over the home button and the 14th target from Discapnet website highlighted on the bottom right side.

distributed equally between the Discapnet (2015) and Gipuzkoa (2015) websites. After completing each block of tasks for a particular cursor variant, a semi-structured interview was conducted in order to gather subjective assessments from participants about that cursor variant.

After completing all 3 blocks of experimental tasks with each cursor variant, participants were asked to rank them from most to least favourite for web browsing purposes. Experimental sessions lasted between 1 and 2 h (30–50 min in the case of participants without MIs). After concluding experimental sessions, participants were rewarded with a voucher worth 25€ for their collaboration in the study.

4.6. Measuring cursors usability

Two different methods were used to measure the usability of the 3 cursor variants tested in this study. On one hand, performance achieved by participants with each cursor variant on target acquisition tasks was studied by means of several cursor path evaluation measures. In this way, the following cursor measurements proposed in the literature (MacKenzie et al., 2001; Keates et al., 2002; Hwang et al., 2004) were used to calculate the efficiency and efficacy achieved on each trial of target acquisition tasks:

- *Movement time (MT)*: the time interval from clicking the home button until target link is selected. The MT corresponds to total time needed to complete a trial, and was calculated based on timestamps of events recorded during experimental sessions.
- *Pointing time (PT)*: the time interval from when the on-screen cursor starts moving until it finally stops before the target link is selected. The PT corresponds to 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 timestamps of events recorded during experimental sessions.
- *Clicking time (CT)*: the time interval from when the on-screen 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 timestamps of events recorded during experimental sessions.
- *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 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:

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

- *Curvature index (CI)*: the ratio of *DT* and 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, while growing values shows increasing deviations. The CI was calculated based on computed DT for a trial and the corresponding distance between first and last cursor location.
- *Number of pauses (NP)*: the times the cursor stops along the pointing trajectory. The NP represents the number of 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 a high number means the user has more difficulties to select that target. The NP was calculated based on the time interval between consecutive cursor motion events, considering intervals equal to or greater than 100 ms as a pause.

On the other hand, satisfaction of study participants with each cursor variant was collected by means of questionnaires based on the System Usability Scale (Brooke, 1996) and the NASA TLX (Hart and Staveland, 1988). In this way, participants provided their subjective assessments for each cursor variant based on the following 8 categories that were rated on a 7-point Likert scale (from strongly positive to strongly negative):

- *Learnable*: How easy was it to learn to use this cursor variant?
- *Memorable*: How easy was it to remember how to use this cursor variant?
- *Accurate*: How accurate was this cursor variant in selecting links?
- *Easy to use*: How easy was it to use this cursor variant to select links?
- *Effortless*: How would you describe the level of effort you need to make with this cursor variant to select links?
- *Natural*: How natural was it to use this cursor variant to select links?
- *Fun*: How much fun was it to use this cursor variant for browsing the Web?
- *Not frustrating*: How would you describe your level of frustration when using this cursor variant to select links?

To conclude, after completing experimental tasks with all 3 cursor variants, participants were also asked to rank them from most to least preferred choice for browsing the Web. Promising preliminary results were obtained from these subjective assessments of the participants (Pérez et al., 2016).

5. Results

In the following subsections we analyse the data collected from participants during experimental sessions. In the first subsection we study how participants leveraged both virtual cursors, explain the filtering process to remove invalid trials, and discuss some implications found. In the following subsection we analyse target acquisition tasks based on several cursor measurements in order to compare the effectiveness and efficiency of the different user groups with each cursor variant tested. Finally, we present a qualitative analysis about participants' satisfaction with each cursor variant based on their responses gathered in the interviews.

5.1. Use of cursor variants and data cleaning

Each of the 15 participants in the study completed 48 target acquisition trials with each of the 3 cursor variants tested (cross, area and original cursor), resulting in a total of 2160 trials. Cursor trajectories gathered in the experimental sessions were analysed in order to filter invalid trials, and thus obtain meaningful measurements of targets acquisition tasks. Below, we analyse the use of each virtual cursor along target acquisition task to understand the acceptance of both assistances by participants.

As we have explained before, the cross cursor enables to shorten link selection time by reducing pointing trajectory and presenting single-letter shortcuts for links at reach of the virtual cursor. Considering the keyboard approach of the cross cursor and the difficulties that some participants had to access this device, they could also use this virtual cursor with standard pointing and clicking (i.e., without leveraging shortcuts) if it was easier for them this way. Table 2 shows for each user group the usage of shortcuts with the cross cursor for assisting link selection, in comparison with standard pointing and clicking. While all participants from the KU group leveraged the cross cursor help to

Table 2
Usage of cross cursor shortcuts on target acquisition task, ordered by user group. The distribution within each group is displayed below the total and percentage values.

	Cross cursor		
Group	*Participants*	*Total trials*	*Assistance usage*
KU	4	192	191 (99.5%)
JU	5	240	50 (20.8%)
MU	6	288	53 (18.4%)

Table 3
Target selections completed from distance for each virtual cursor and user group. The distribution within each group is displayed below the total and percentage values.

Cross cursor			
Group	*Participants*	*Total trials*	*Outside selections*
KU	4	192	184 (95.8%)
Area cursor			
Group	*Participants*	*Total trials*	*Outside selections*
KU	4	192	147 (76.6%)
JU	5	240	124 (51.7%)
MU	6	288	101 (35.1%)

Table 4
Number of invalid trials filtered from target acquisition task, ordered by user group, cursor variant, and type of issue. The distribution within each group is displayed below the total and percentage of filtered trials.

Keyboard users group (KU)			
Cursor	*Misses*	*Erroneous*	*Outliers*
Original	7 (3.6%)	3 (1.6%)	11 (5.7%)
Area	5 (2.6%)	4 (2.1%)	6 (3.1%)
Cross	11 (5.7%)	8 (4.2%)	7 (3.6%)
Joystick & trackball users group (JU)			
Cursor	*Misses*	*Erroneous*	*Outliers*
Original	18 (7.5%)	1 (0.4%)	10 (4.2%)
Area	10 (4.2%)	2 (0.8%)	11 (4.6%)
Mouse users group (MU)			
Cursor	*Misses*	*Erroneous*	*Outliers*
Original	22 (7.6%)	0 (0%)	10 (3.5%)
Area	4 (1.4%)	1 (0.3%)	12 (4.2%)

complete target acquisition tasks (99.5%), participants from JU and MU groups generally preferred to move the virtual cursor pointer over links to perform standard pointing and clicking (respectively 79.2% and 81.6%) as with the original unassisted cursor. Only one participant from the JU group (JU1) and another from the MU group (MU2) used repeatedly the cross cursor shortcuts to complete target acquisition tasks. For this reason, subsequent analyses presented about the cross cursor refer only to the keyboard users group (KU).

Both virtual cursors studied (the cross and area cursor) enable link section without needing to hover the cursor pointer over targets to perform a click. In this respect, Table 3 shows the number of target acquisition trials completed by selecting the link from outside the target area (i.e., taking advantage of the cursor assistance), ordered by virtual cursor variant and user group. The KU group of keyboard users as pointing device achieved the highest rates of target selection from distance, both with the cross cursor (95.8%) and the area cursor (76.6%). Joystick and trackball users (JU group) completed on average slightly more than half of the trials with the area cursor (51.7%) by clicking outside of the target link. On the contrary, the MU group participants without MIs were the ones that, on average, most frequently clicked over the target links with the area cursor without leveraging the virtual cursor assistance (64.9%). Results on Tables 2 and 3 show a good acceptance and use of the novel cross cursor by the KU group participants, whereas participants of the other 2 groups (JU and MU groups) generally avoided using this assistance. On the other hand, on average, the 3 groups of participants took advantage of the area cursor to assist link selection, although with different results (Table 3). All participants of the KU group leveraged regularly the area cursor assistance, with users KU2 and KU1 achieving the highest (83.3%) and the lowest (66.7%) rates of this group, respectively. The participants of the JU group also leveraged the area cursor assistance, although unevenly, with user JU1 achieving the highest rate (81.3%) and JU4 the lowest (27.1%). In contrast, several MU group participants barely used the area cursor assistance and clicked over the target area in most of the trials, as for instance user MU6 (95.8%) and MU2 (91.7%). These results, as expected, show a greater preference for the virtual cursors by participants with MIs (KU and JU groups) than by participants without MIs (MU group).

Invalid trials were removed for subsequent analyses of cursor trajectories and corresponded to misses on target acquisition tasks, erroneous trials including unexpected events on pointing and clicking interactions, as well as outlier trials. For the cross cursor, a missed trial occurred when one or more additional letter keystrokes were registered before target selection. For the area and original cursors, a missed trial occurred when one or more additional clicks were registered before target selection. Erroneous trials were defined as those including user interactions not related with the target acquisition task, and corresponded to any event other than the cursor move followed by a target selection (a standard click for the area and original cursors, or a letter keystroke for the cross cursor shortcut). Events that allowed identifying erroneous trials include the use of the Control, Shift, Escape, and Arrow keys (by the KU group), the use of the Enter key and the reload page button (by the JU group), or scrolling the page (by the MU group). We also removed outlier trials corresponding to cases where the movement time (MT) divided by the index of difficulty (ID) was two standard deviations or more away from participant's mean with the corresponding cursor variant. To calculate the ID of each trial we used the following equation for bivariate pointing (1) which considers both target width W and height H, as well as distance D from starting point to target (Accot and Zhai, 2003). A similar calculation was made to normalize other studied cursor measurements related to target acquisition as detailed in the following subsection. Table 4 shows the number of invalid trials filtered this way from target acquisition tasks, for each cursor variant, user group, and issue type.

$$ID = \log_2\left(\sqrt{(D/W)^2 + \eta\,(D/H)^2} + 1\right) \quad (1)$$

For keyboard users as pointing device (KU group), the data cleaning process resulted in removing 10.9% of the trials completed with the original cursor, 7.8% with the area cursor, and 13.5% with the cross cursor. Taking into account only missed and erroneous trials, the filtered data was 5.2%, 4.7%, and 9.9%, respectively. These results show a slight improvement with the area cursor compared to the original cursor, although this was not repeated by all KU group participants (KU2 and KU3 in Table 4). With the cross cursor, in contrast, the number of invalid trials increased compared to the other two cursors tested.

For joystick and trackball users (JU group), the data cleaning process resulted in removing 12.1% of the trials completed with the

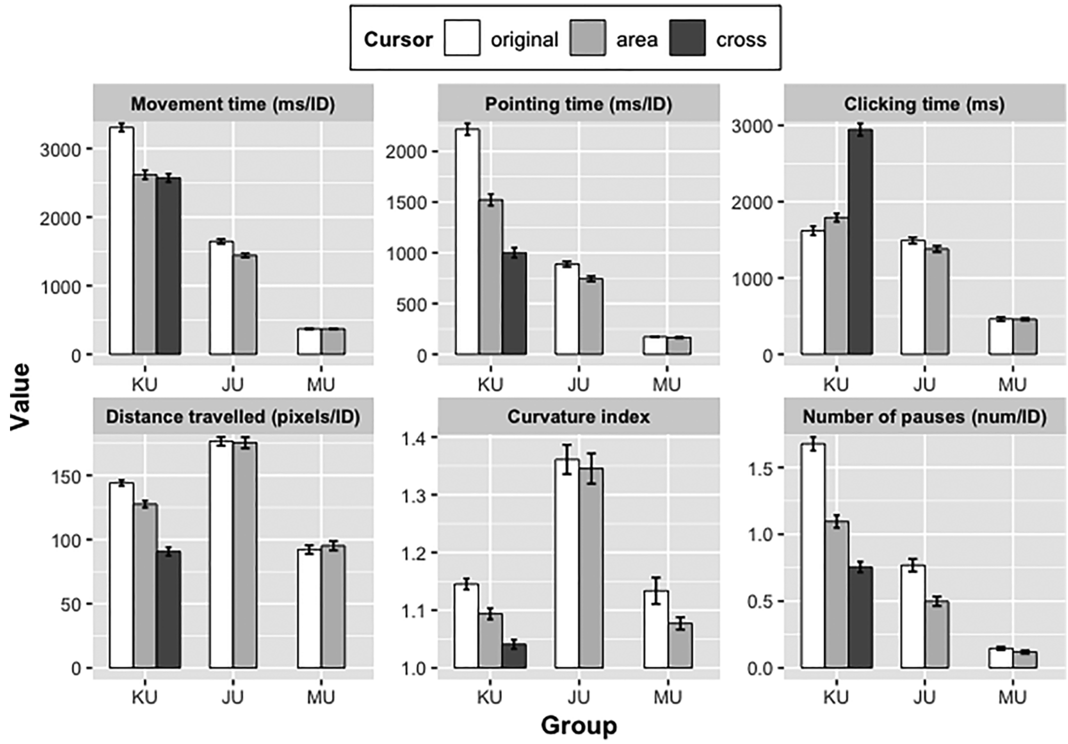

Fig. 8. Mean values of each cursor measure studied by users group and cursor variant tested. Error bars represent ± 1 standard error (SE).

original cursor and 9.6% with the area cursor. Taking into account only missed and erroneous trials, the filtered data was 7.9% and 5%, respectively. These results show a decrease of invalid trials with the area cursor compared to the original cursor.

For participants without MIs (MU group), the data cleaning process resulted in removing 11.1% of the trials completed with the original cursor, and 5.9% with the area cursor. Taking into account only missed and erroneous trials, the filtered data was 7.6% and 1.7%, respectively. These results show an improvement with the area cursor compared to the original cursor, which was repeated by all MU group participants.

In general terms, the 3 groups of participants reduced the miss rate on target acquisition trials with the area cursor in comparison with the original cursor. With the cross cursor, in contrast, KU group participants increased the number of missed and erroneous trials.

5.2. Cursor accuracy measures

We used the following 6 features to measure effectiveness and efficiency of participants on pointing & clicking tasks with each cursor tested: movement time (MT), pointing time (PT), clicking time (CT), distance travelled (DT), curvature index (CI) and number of pauses (NP). These accuracy measurements have only been applied to interaction data gathered from target acquisition tasks, in order to study intended cursor movements of link selection and avoid unintended moves that appear during free navigation in searching tasks.

Firstly, measures about MT, PT, DT and NP were normalized as trials of the target acquisition task had different link sizes and distances to starting point. To do this, we divided results calculated for each trial by its index of difficulty (ID) (1) as mentioned before. Results concerning CI and CT were not normalized, since the former is a ratio that considers distances (travelled and straight-line between starting and ending points) of each trial, while the latter depends on pointing device and cursor variant used rather than on presentation of the GUI.

To compare the 3 cursors tested (original, area and cross) we studied performance of each participant separately, as well as average values achieved by each group of users: the keyboard users as pointing device (KU group), the joystick and trackball users (JU group), and the mouse users without MIs (MU group). In the following 6 subsections we address each cursor measure studied, comparing the average results achieved by each user group (Fig. 8), as well as analysing general trends on per-participant boxplots calculated for each user group (Fig. 9 for KU group, Fig. 10 for JU group, and Fig. 11 for MU group). Considering the small size of our sample (something generally inherent in studies involving people with disabilities), statistical analyses were avoided.

5.2.1. Movement time (MT)

On average, the KU group improved the MT with both virtual cursors (Fig. 8 top left), achieving a slightly better result with the cross cursor than with the area cursor. Mean values with the cross and area cursor were 2571 ms/ID and 2618 (SD = 765 and 870) respectively, whereas 3306 (SD = 773) with the original cursor. The JU group, on average, achieved the best MT result with the area cursor (mean = 1442 ms/ID, SD = 458) followed by the original cursor (mean = 1644, SD = 484). The MU group, on average, got the same MT results with the area cursor (mean = 370 ms/ID, SD = 131) and the original cursor (mean = 370, SD = 167).

All participants from KU group achieved best median values of MT with the cross cursor (Fig. 9 top left), followed by the area cursor and the original cursor, second and third respectively for all the group participants. All JU group participants (Fig. 10 top left), and two of the six participants from MU group (MU2 and MU4 in Fig. 11 top left) got lowest median values of MT with the area cursor than with the original cursor.

5.2.2. Pointing time (PT)

On average, the KU group got the best PT result (Fig. 8 top centre) with the cross cursor (1000 ms/ID, SD = 752), followed by the area cursor (1522, SD = 753) and the original cursor (2217, SD = 626). The JU group, on average, achieved the best PT result with the area cursor (mean = 744 ms/ID, SD = 381) followed by the original cursor (mean = 889, SD = 381). The MU group, on average, got similar PT results with the area cursor (mean = 165 ms/ID, SD = 97) and the

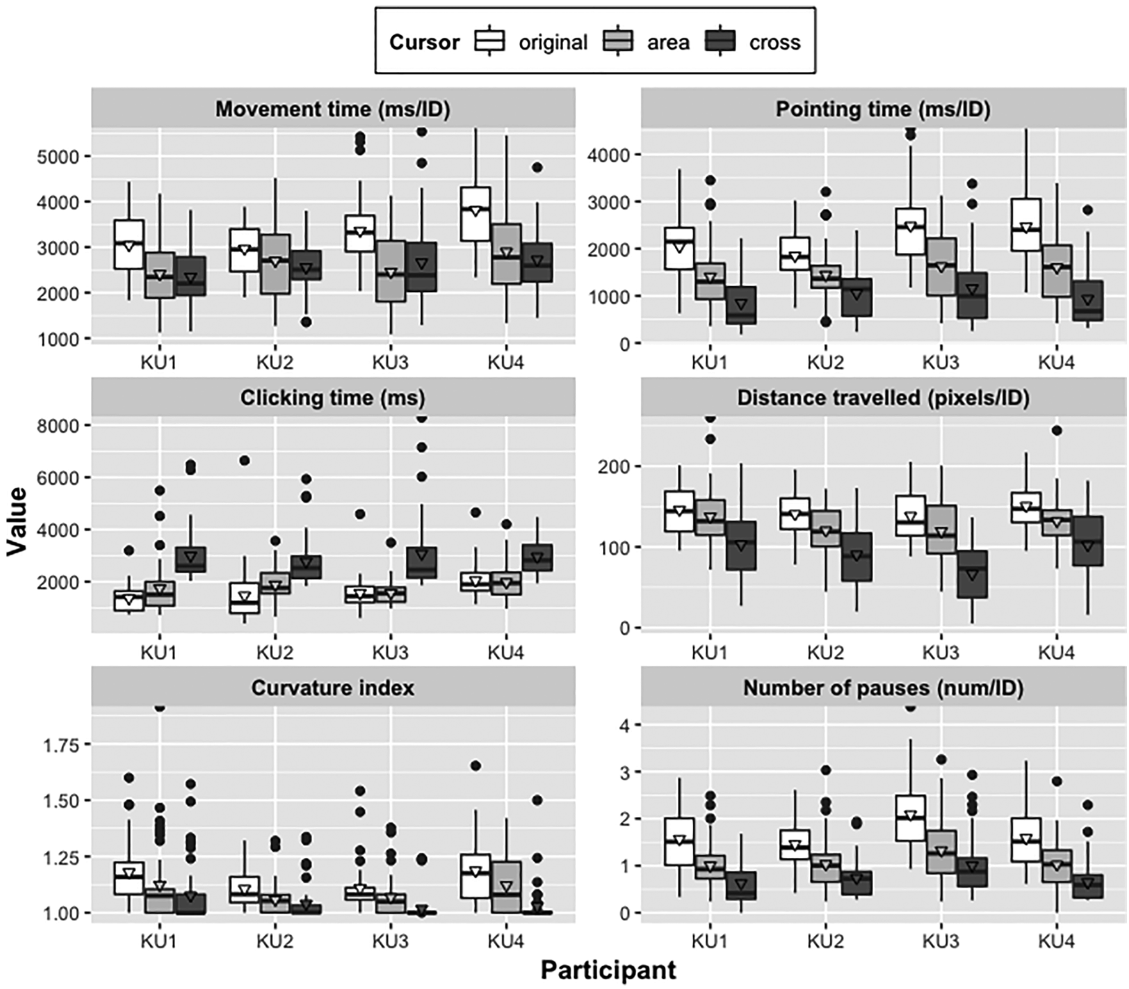

Fig. 9. Boxplots collection from KU group showing distribution of measures studied for each participant and cursor tested. Band and triangle inside each box represent the corresponding median and mean values respectively.

original cursor (mean = 172, SD = 78).

All participants of the KU group achieved best median PT values with the cross cursor (Fig. 9 top right), followed by the area cursor and the original cursor, second and third respectively for all the group participants. Four of the five JU group participants (JU1, JU2, JU4 and JU5 in Fig. 10 top right), and three of the six MU group participants (MU1, MU2 and MU4 in Fig. 11 top right), got lower median values of PT with the area cursor than with the original cursor.

5.2.3. Clicking time (CT)

On average, the KU group obtained the worst CT result (Fig. 8 top right) with the cross cursor (2945 ms, SD = 1032), followed by the area cursor (1791, SD = 717), and the original cursor (1618, SD = 773). For the JU group, a slightly better CT value was achieved with the area cursor (mean = 1380 ms, SD = 590) than with the original cursor (mean = 1491, SD = 593). The MU group got, on average, similar CT results with the area cursor (mean = 459 ms, SD = 269) and the original cursor (mean = 463, SD = 419).

According to median values of CT, all KU group participants obtained the worst results with the cross cursor (Fig. 9 middle left), whereas best results every time corresponded to the original cursor, followed by the area cursor. Four of the five JU group participants (JU1, JU2, JU4 and JU5 in Fig. 10 middle left), and three of the six MU group participants (MU2, MU4 and MU6 in Fig. 11 middle left) got best median values of CT with the area cursor than with the original cursor.

5.2.4. Distance travelled (DT)

On average, the KU group obtained the best DT result (Fig. 8 bottom left) with the cross cursor (mean = 91 px/ID, SD = 42), followed by the area cursor (mean = 128, SD = 35) and the original cursor (mean = 144, SD = 30). The JU group got almost identical DT results with the area cursor (mean = 175 px, SD = 64) and the original cursor (mean = 176 px, SD = 49). Also the MU group got almost identical DT results with the area cursor (mean = 95 px/ID, SD = 59) and the original cursor (mean = 92, SD = 54).

All participants from KU group obtained best median values of DT with the cross cursor (Fig. 9 middle right), followed by the area cursor and the original cursor, second and third respectively for all the group participants. Three of the five JU group participants (JU1, JU2 and JU5) got lower median values of DT with the area cursor than with the original, whereas JU4 got identical median values with both variants (Fig. 10 middle right). Three of the six MU group participants (MU1, MU2 and MU4) got lower median values of DT with the area cursor than with the original cursor (Fig. 11 middle right).

5.2.5. Curvature index (CI)

On average, the KU group obtained the best CI result (Fig. 8 bottom centre) with the cross cursor (mean = 1.04, SD = 0.1), followed by the area cursor (mean = 1.09, SD = 0.13) and the original cursor (mean = 1.15, SD = 0.13). The JU group got similar CI results with the area cursor (mean = 1.35, SD = 0.39) and the original cursor (mean = 1.36, SD = 0.37). The MU group, on average, achieved the

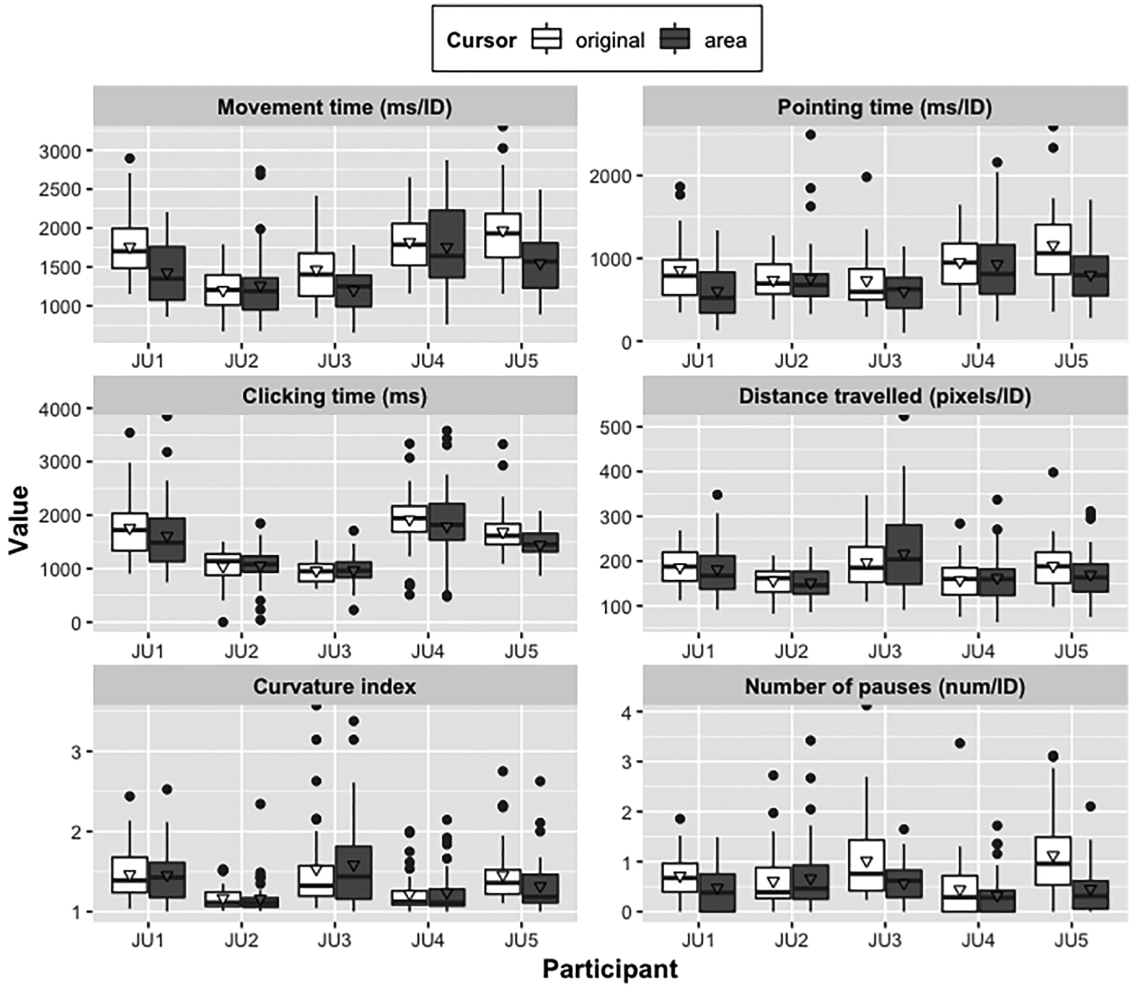

Fig. 10. Boxplots collection from JU group showing distribution of measures studied for each participant and cursor tested. Band and triangle inside each box represent the corresponding median and mean values respectively.

best CI result with the area cursor (mean = 1.08, SD = 0.18), followed by the original cursor (mean = 1.13, SD = 0.37).

All participants of the KU group achieved best median values of CI with the cross cursor (Fig. 9 bottom left), followed by the area cursor and the original cursor, second and third respectively for all the group participants. Two of the five JU group participants (JU4 and JU5) got better median values of CI with the area cursor than with the original, whereas JU2 got identical median values with both variants (Fig. 10 bottom left). Three of the six MU group participants (MU1, MU3 and MU4) got better median values of CI with the area cursor than with the original cursor (Fig. 11 bottom left), whereas the other 3 participants obtained same median values with both cursor variants.

5.2.6. Number of pauses (NP)

On average, the KU group achieved the best NP result (Fig. 8 bottom right) with the cross cursor (0.75 sum/ID, SD = 0.51), followed by the area cursor (1.1, SD = 0.62) and the original cursor (1.68, SD = 0.67). The JU group achieved the best NP result with the area cursor (mean = 0.5 sum/ID, SD = 0.51), followed by the original cursor (mean = 0.77, SD = 0.69). The MU group got a slightlty better NP result with the area cursor (mean = 0.12 sum/ID, SD = 0.21) than with the original cursor (mean = 0.15, SD = 0.2).

All KU group participants achieved best median values of NP with the cross cursor (Fig. 9 bottom right), followed by the area cursor and the original cursor, second and third respectively for all the group participants. Four of the five JU group participants (JU1, JU3, JU4 and JU5) got better median values of NP with the area cursor than with the original (Fig. 10 bottom right). One of the six MU group participants (MU2) got better median value of NP with the area cursor than with the original (Fig. 11 bottom right), whereas the other 5 participants obtained same median values with both cursor variants.

5.3. Participants satisfaction

Fig. 12 includes bar graphs for each of the 8 categories of the satisfaction questionnaire, showing distribution of responses by each group of participants (KU, JU and MU) about cursor variants tested (original, area and cross).

The cross cursor obtained the worst results in the learnable category from JU and MU groups whereas it was highly rated by participants of the KU group. The area cursor obtained the best values from the JU group.

The original cursor obtained the best responses for the memorable category, which is not surprising as all the participants were already accustomed to it. However, the values obtained by both enhanced cursors are worthy of further attention, especially the ratings given to the cross cursor by the KU group participants and the ones given to the area cursor by the JU group participants.

Both groups of participants with disabilities (KU and JU) gave higher ratings to the area cursor in the accurate category. Nevertheless, half of the participants in the KU group preferred the cross cursor when asked to rank the cursor variants. Three participants without disabilities (MU group) also indicated their preference for the area cursor in the accurate category.

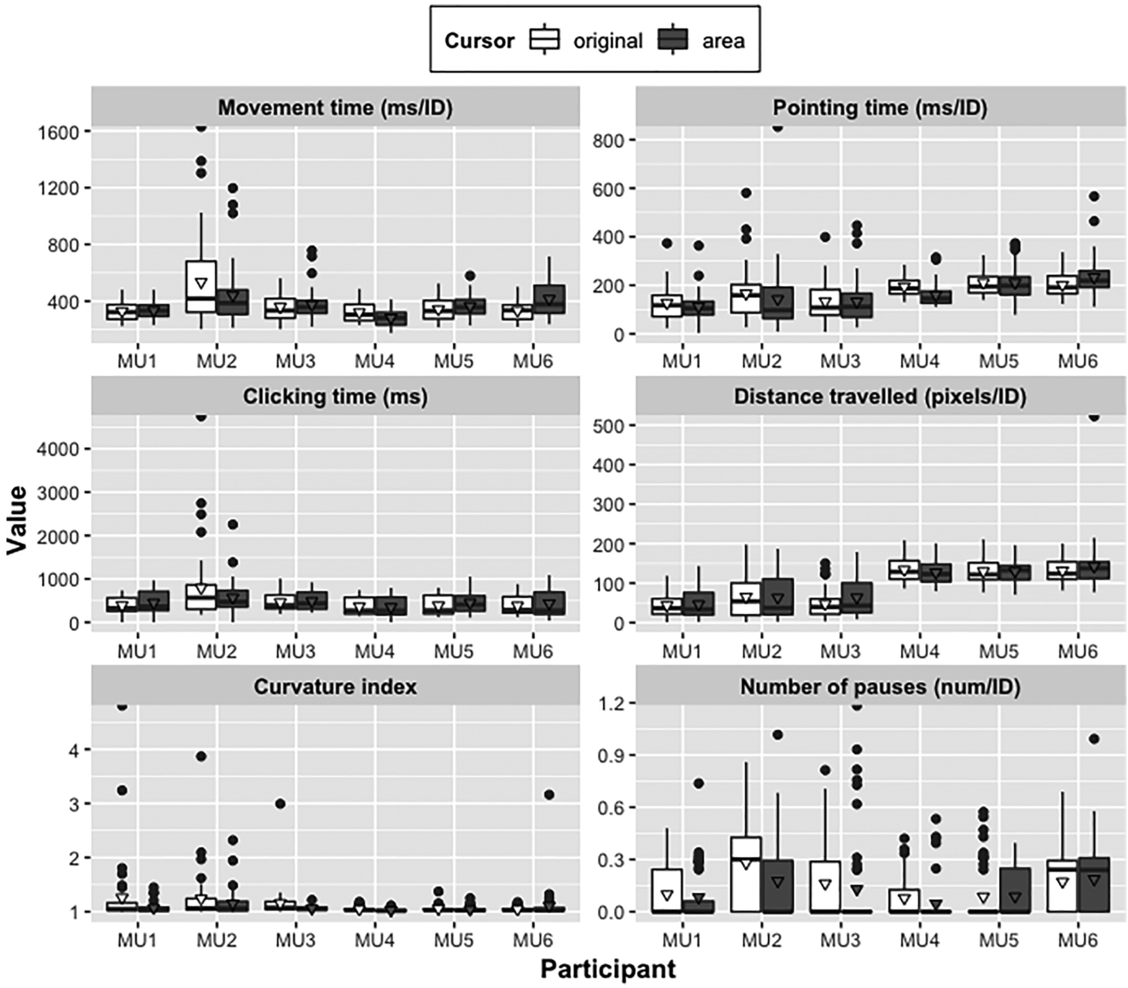

Fig. 11. Boxplots collection from MU group showing distribution of measures studied for each participant and cursor tested. Band and triangle inside each box represent the corresponding median and mean values respectively.

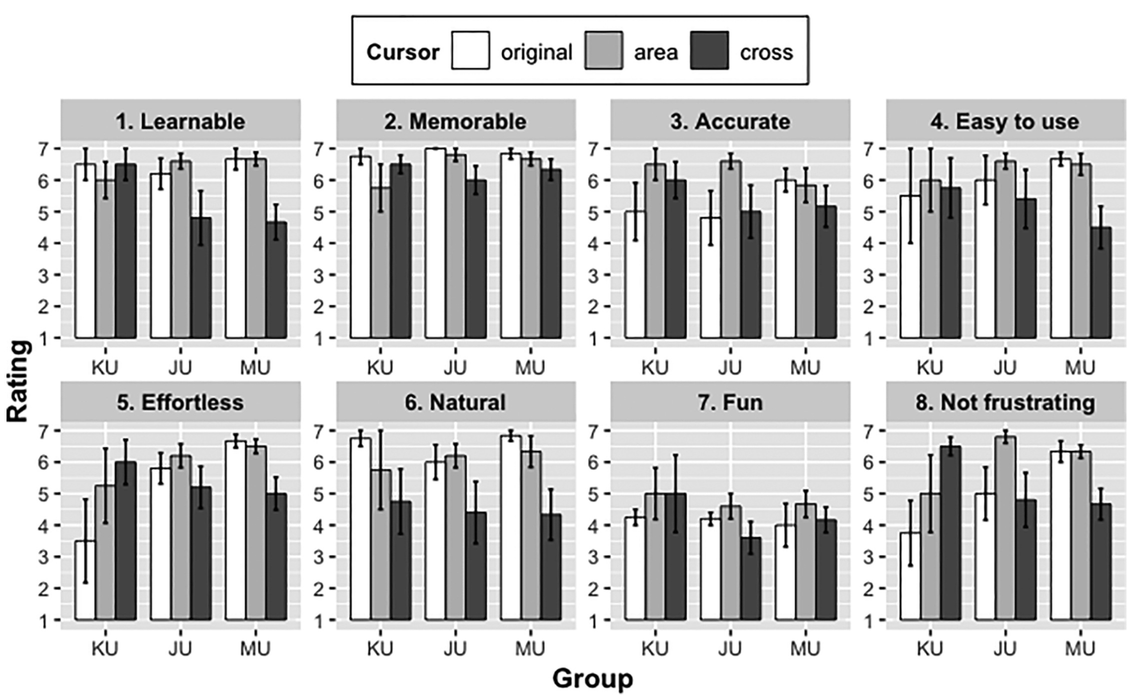

Fig. 12. Average ratings by users group for each cursor tested (Likert scale from 1 – strongly negative to 7 – strongly positive). Error bars represent ± 1 standard error (SE).

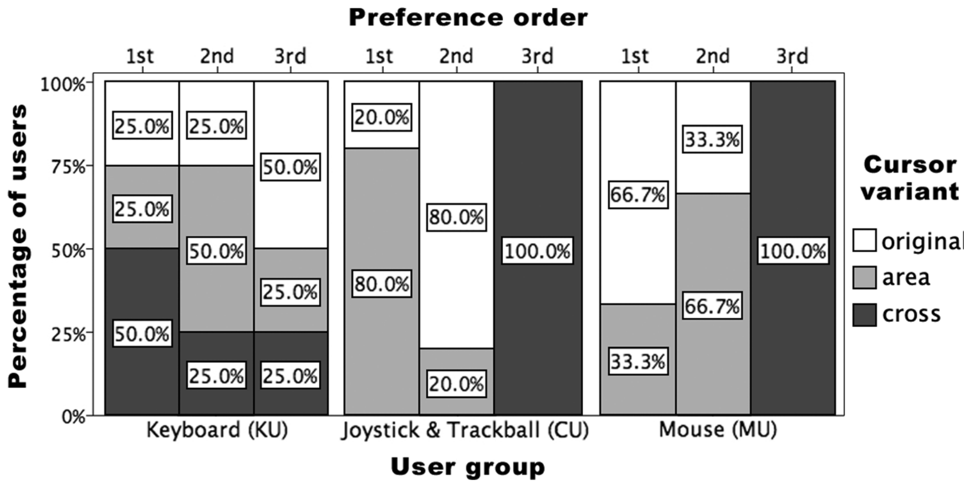

Fig. 13. Ranking by user group for preferred cursor variant for web browsing.

Regarding the easy to use category, the area cursor is the best rated option by participants with disabilities. The cross cursor is the last choice in the ranking for participants from JU and MU groups, whereas the first one for half of participants in the KU group.

Values obtained for the effortless category show a clear preference for the area cursor from the JU group, for the cross cursor from the KU group and for the original cursor from the MU group. However, the area variant also obtained high values from participants without disabilities.

The original cursor is highly rated in the natural category by the different user groups. Half of the participants in the KU group ranked the cross cursor second, whereas it was the last ranked option for participants in the other groups.

Participants felt some insecurity when rating the fun category and values given to the cursor variants did not differ significantly. However, the area cursor obtained the best results from the three groups, as it was something new they were trying and they found it to be a friendly cursor option. Regarding the rankings obtained in this category, participants in the KU group ranked the cross cursor as the first option (75%) followed by the area cursor (50%). 50% of the JU group selected the area cursor as the first option whereas the cross cursor was more often the lowest ranked option (80%). Participants in the MU group mainly selected the area cursor in first place and the cross cursor as last option.

There are clear differences between values given by participants with disabilities in the not frustrating category. The cross cursor was highly rated by users in the KU group (6.5), the area cursor was the one obtaining best values from users in the JU group (6.8), and the area and original cursors obtained the same mean value (6.3) for users without disabilities. Regarding the ranking of cursor variants in this category, the original cursor was the last option for 75% of the KU group and the cross cursor was the lowest ranked option for the entire JU group.

Fig. 13 shows the overall values of cursor preferences by user group. As can be seen, 50% of participants in the KU group preferred the cross cursor, 80% of participants in the JU group preferred the area cursor and 66.7% of participants in the MU group preferred the original cursor.

6. Discussion

6.1. Keyboard users group (KU)

Results presented in Figs. 8 and 9 show that the KU group participants improved almost every performance measure studied (except the clicking time) using either of the 2 virtual cursors tested (cross or area) instead of the original cursor. In addition, all participants of the KU group obtained, on average, better results with the cross cursor than with the area cursor for every measure (except CT), highlighting the pointing time, distance travelled, curvature index, and number of pauses. These results proved that the cross cursor was the most beneficial variant for the KU group participants on target acquisition tasks, reducing both distance and difficulties along cursor trajectory to a greater extent than the area cursor.

As expected, the 4 participants of the KU group worsen the CT using the cross cursor instead of the original or area cursor (Fig. 9 middle left). Unlike these 2 cursors (original and area) with which keyboard users always use the same key to select a link, the cross cursor requires to keystroke the appropriate letter to leverage the virtual cursor assistance. This way of interacting with the cross cursor entailed larger CT compared to the other 2 variants tested, but as results show, all KU group participants still achieved better total MT results (which also includes the CT) with the cross cursor (Fig. 9 top left).

Considering that the cross cursor implements a novel target selection mechanism for the participants, and that experimental sessions lasted no more than 2 h, we think that keyboard users could improve their performance with this virtual cursor after a longer learning period. For instance, Fig. 14 shows how KU group participants performed differently on target acquisition tasks, when pointing with the original cursor (Fig. 14 top row) compared with both virtual cursors (area – middle row and cross – bottom row). It is striking that even though participants KU1, KU2 and KU4 leveraged the cross cursor selecting links from distance (Fig. 14, 1st, 2nd and 4th column, bottom row), each of them carried on pointing towards targets similarly as with the original and area cursors. By contrast, participant KU3 was able to reduce travelled distances even further with the cross cursor, by changing his pointing behaviour with respect to the original cursor and aiming across the targets' width with only horizontal cursor movements (Fig. 14, 3rd column, bottom row). We can affirm that participant KU3 was able to point with the cross cursor optimally and travel shorter paths (Fig. 9 middle right), and that other participants from this group might approach this method if they were provided with a longer learning period.

The study of invalid trials filtered from target acquisition task (Table 4) provided additional insights about the virtual cursors tested. For the KU group, the number of missed and erroneous trials increased with the cross cursor (9.9%) compared to the original (5.2%) and area cursor (4.7%). This was expected, as target selection based on shortcuts that implements the cross cursor is more cognitively and physically demanding than the other 2 variants tested, and thus error-prone. The highest rate for the KU group corresponded to misses with the cross cursor (5.7%), in comparison with the original (3.6%) and area cursor (2.6%). Missed selections in the Web can bring the user unintentionally to unwanted web pages, making recovery back to the original page particularly tedious and time consuming for people with MIs. Despite

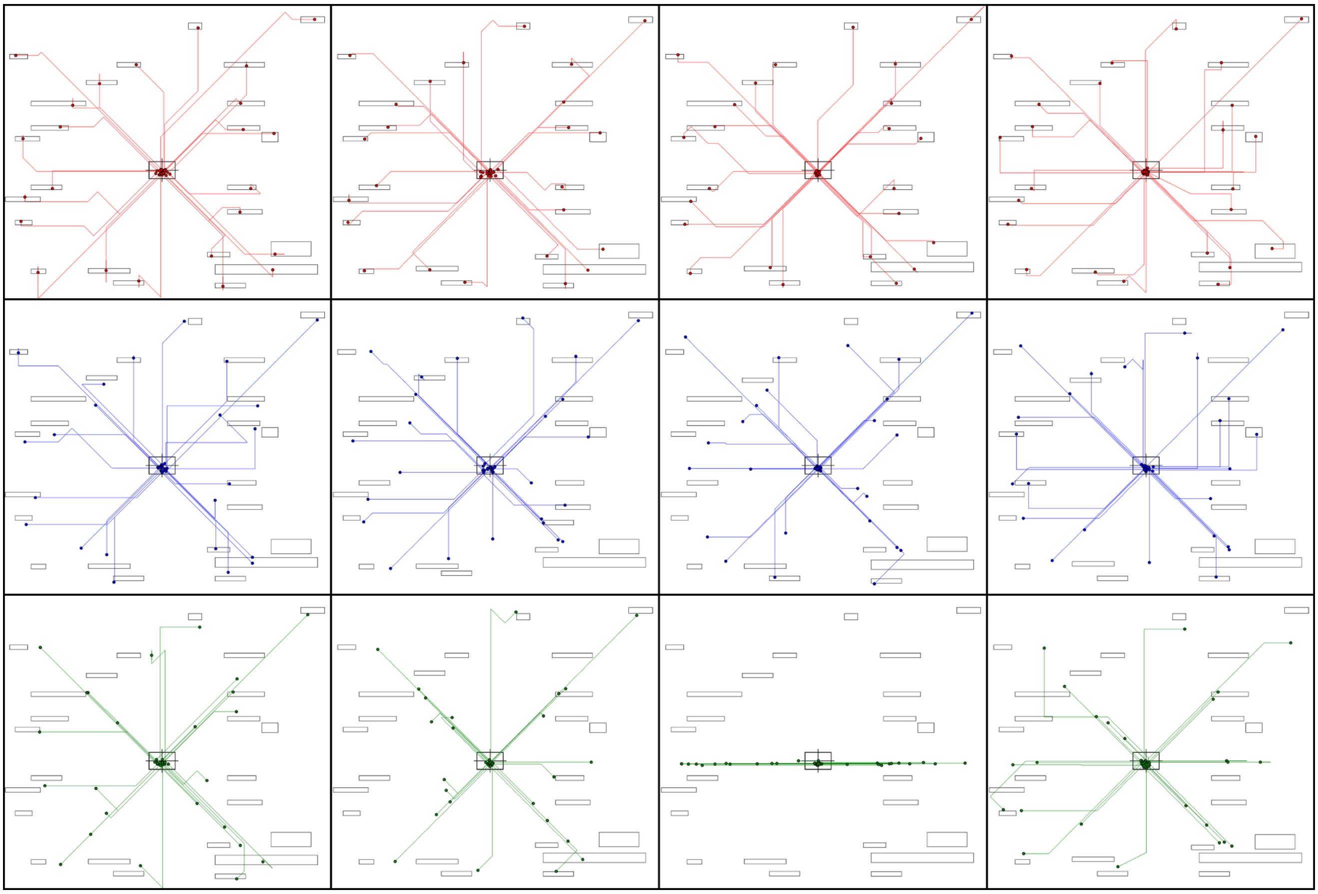

Fig. 14. Cursor trajectories of each KU group participant (each column corresponds to a user: KU1 to KU4 from left to right) with cursors studied (top row – original, middle – area and bottom – cross) in target acquisition trials of the first website (Discapnet).

these results about missed trials, the KU group participants positively assessed the cross cursor and, in general terms, felt comfortable with this new virtual cursor. Although the miss rate obtained by the KU group with the cross cursor was not high, we think that keyboard users could also improve at this point with a longer period of use of the virtual cursor. As pointed out before, the lowest miss rate of the KU group corresponded to the area cursor. Even though KU group participants did not achieved the best results with the area cursor, further research should study an improved version of the cross cursor with a larger than normal activation area.

According to subjective assessments provided by KU group participants, the cross cursor was, on average, the preferred option for browsing the Web from among the 3 variants tested (Fig. 13). Despite that, one keyboard participant (KU2) ranked the cross cursor as the least useful variant. She mentioned not remembering she could click distant links by automatically provided keystrokes. Nevertheless, she affirmed that she found the cross cursor very useful and was of the opinion that it could be beneficial to her in the long term once she got accustomed to it. The cross cursor also obtained the best average subjective assessments from keyboard participants (Fig. 12) for significant categories such as effortless and not frustrating, as well as generally good average scores for the remaining categories.

Participant KU2 declared, *"with the original cursor it is difficult to aim at small targets, whereas with the area variant this problem was reduced. Although it is easier to aim targets with the area variant, you have to pay attention on which link is highlighted to leverage this virtual cursor".* Participant KU3 said he *"would like to use the cross variant as you do not have to move the cursor so much, you only have to press one letter and that's all"*. Participant KU4 declared *"I do not like the area variant as I found issues when links are close together"*. On the contrary, KU4 said she *"would use the cross variant, although I found tiring to select each time a shortcut letter and I would need time to get used to"*.

6.2. Joystick and trackball users group (JU)

The JU group improved, on average, all cursor measures with the area cursor compared to the original (Fig. 8), although larger benefits corresponded to movement time, pointing time, clicking time and number of pauses. According to the distribution of results per-participant (Fig. 10), all 5 JU group participants improved the MT with the area cursor, whereas only 4 participants improved the PT, CT and NP, 3 improved the DT, and 2 improved the CI. In addition, these results show that only one participant of the JU group (JU5) improved, on average, all cursor measures with the area cursor compared to the original cursor.

According to subjective assessments provided by JU group participants (Fig. 12), the area cursor received, on average, better scores than the other 2 variants tested for 7 out of 8 categories (the exception being memorable). Best results corresponded to the categories accurate, effortless and not frustrating, obtaining, on average, bigger differences with respect to the original cursor. As for the preferred variant for web browsing (Fig. 13), 4 out of 5 participants from the JU group rated the area cursor as their favourite cursor. Concerning the cross cursor, it was unanimously selected as the least preferred variant for web browsing by all 5 participants from the JU group (Fig. 13), as well as receiving, on average, the worst rating for all satisfaction categories (Fig. 12). In addition, only one participant from the JU group (JU1) used the cross cursor shortcuts to complete target acquisition task (Table 2).

Results on performance and satisfaction of participants from the JU group revealed that the area cursor, initially proposed to assist joystick and

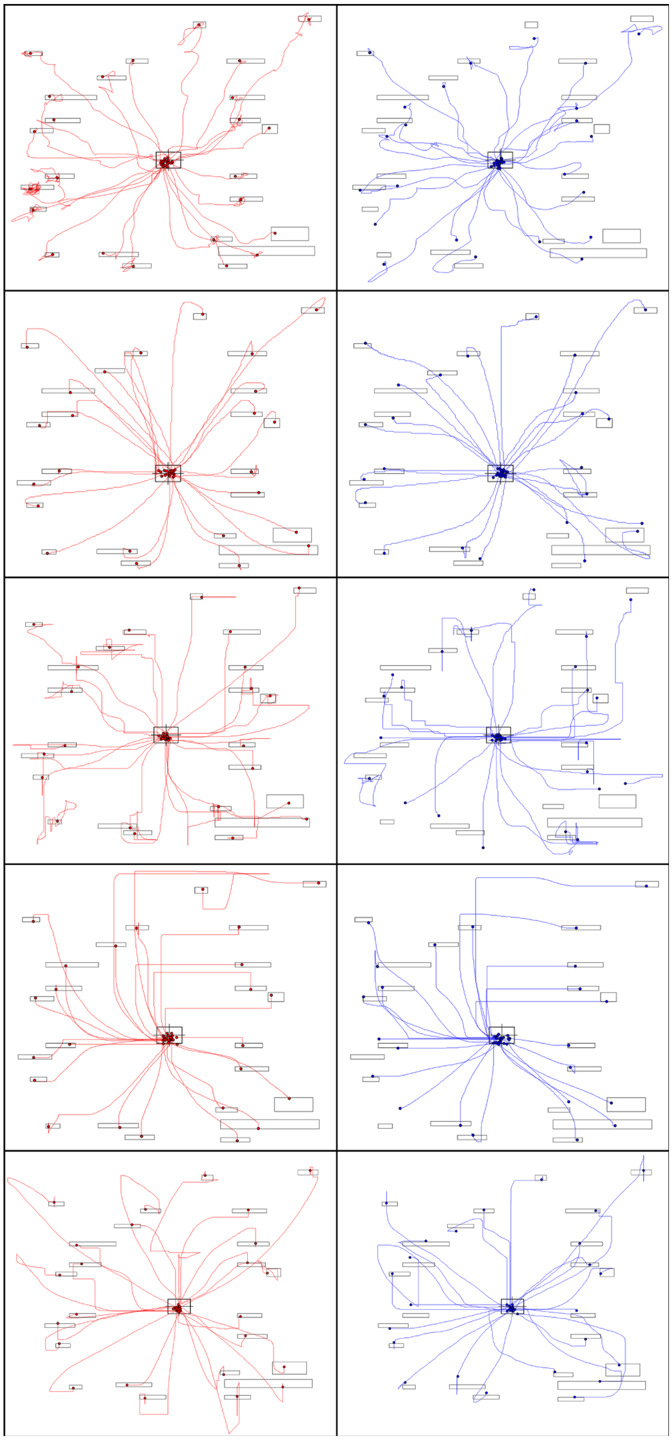

Fig. 15. Cursor trajectories of each participant of the JU group (each row corresponds to a user: JU1 to JU5 from top to bottom) with cursors studied (left – original and right – area) in target acquisition trials of the first website (Discapnet).

trackball users, was the most beneficial and preferred variant on average for this group of participants. Despite positive results with the area cursor, participants from the JU group were able to take advantage of this cursor variant, on average, on around half of the target acquisition trials (51.7%) by clicking outside of target link (Table 3). Furthermore, the JU group participants leverage the area cursor assistance unevenly, with user JU1 achieving the highest rate (81.3%) and JU4 the lowest (27.1%).

The right column of Fig. 15 shows how the 5 participants from the JU group performed differently with the area cursor. While participants JU1 and JU3 (Fig. 15, 1st and 3rd row, right) selected the majority of links by clicking outside the targets, JU2 and JU4 (Fig. 15, 2nd and 4th row, right) behaved the opposite. Participants JU2 and JU4 followed a similar point and click behaviour with both the original and the area cursors (Fig. 15, 2nd and 4th row), and on many occasions kept on aiming for the target link with the virtual cursor despite this being unnecessary. By contrast, JU1, JU3 and JU5 were able to leverage the area cursor (Fig. 15, 1st, 3rd and 5th row, right) and mitigate difficulties around the target (Fig. 15, 1st, 3rd and 5th row, left). Considering that the area cursor implements a novel target selection mechanism for participants, and that sessions of this study lasted no more than 2 h, we think that joystick and trackball users could improve their performance with this virtual cursor with the benefit of a longer learning period.

Moreover, several participants stated during interviews that pointing with the area cursor was more difficult when various links were close to the target link, which reduced the cursor activation area and forced them to click within the target area. These distractors around the target reduce the area cursor assistance the closer they are to the target link, resulting in the unassisted original cursor behaviour if the target link is surrounded by distractors at a minimum distance. As information about distractors was not gathered in the interaction log this time, we were not able to take the distractor factor into account in this study when analysing participant performance. In order to consider distractors it would be necessary to have information about their sizes and locations, in a similar way as we do here for the target link.

For participant JU1 *“it was more fun to use the area variant than the other two cursor tested, since this required less precision to select links”* and *“the area variant was also less tiring to use than the original cursor”*. Participant JU1 said about the area cursor that: *“it was easy to use, but it is necessary to be alert on the highlighted link in order to leverage this assistance”*. Participant JU5 declared *“the area cursor was easy to use, and useful for people like us with motor impairments”*. Participant JU4, although she had no significant improvement with the area cursor, declared about the original cursor: *“I usually have difficulties aiming to small links”*.

Regarding the invalid trials filtered from target acquisition task (Table 4), the JU group reduced, on average, the number of missed trials with the area cursor (4.2%) compared to the original cursor (7.5%), which is very desirable to assist link selection to this group of people with MIs. However, to enable more users with MIs to benefit from this assistance, further research should study how to highlight target at reach more conveniently to make it more perceivable for users, and to reduce the cognitive tiredness after prolonged use.

6.3. *Mouse users group (MU)*

As expected, participants without MIs (MU group) were those that perceived less improvement or deterioration in performance when using the area cursor instead of the original cursor (Fig. 8 and Fig. 11). The average results of the MU group (Fig. 8) show that the performance with the area cursor improved compared to the original cursor only for the curvature index, whereas for the rest of cursor measurements, results obtained with both cursor variants (original and area) were very similar. According to the distribution of results per-participant (Fig. 11), 3 of the 6 MU group participants improved with the area cursor in comparison with the original cursor on the PT, CT, DT and CI, whereas 2 participants improved the MT, and only 1 improved the NP.

On average, the area and the original cursor received similar subjective assessments from MU group participants (Fig. 12), although with a slight preference for the latter. The original cursor was selected by 4 of the 6 MU participants as the preferred variant for web browsing (Fig. 13), followed by the area cursor. On the other hand, the cross cursor was unanimously selected as the least preferred variant by all 6 participants from the MU group (Fig. 13), and, on average, received worse ratings for all satisfaction categories except for the fun category

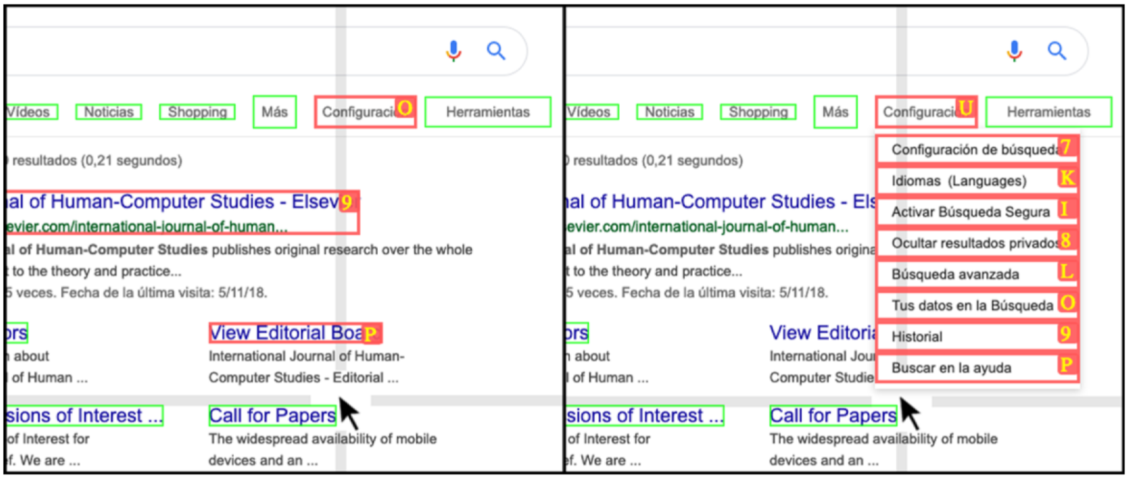

Fig. 16. Accessing the content of a drop-down menu with the cross cursor, without additional mouse movements (left – menu hidden before selection, right – menu expanded after selection).

(Fig. 12). Its keyboard related interaction conflicted with fluent mouse usage, and it was mainly avoided for this reason.

According to participants' comments during following interviews, they proposed some improvements for virtual cursors. Participant MU2 declared about the area cursor that she *"did not like how links were highlighted, and this made me tired during web navigation"*. Participant MU5 said about the area cursor that he *"would reduce its activation area to select this variant as favourite"*, and that *"this assistance was useful for small and isolated links, but not for close links"*. About the cross cursor, MU5 stated, *"it is distracting both the letters displayed next to links and how links are highlighted"*.

Regarding the invalid trails filtered from target acquisition task (Table 4), the MU group of participants without MIs surprisingly reduced the number of missed trials with the area cursor (1.4%) compared to the original cursor (7.6%), getting even greater improvement than the other 2 groups of participants with MIs. In some cases (MU3, MU4 and MU5), the accuracy improvement was achieved by leveraging the area cursor assistance. In other cases (MU6), in contrast, the accuracy improvement was not achieved by leveraging the area cursor assistance, but by reducing the speed of cursor movement.

6.4. Other practical applications of the virtual cursors

In addition to assist standard link selection, we implemented both virtual cursors (area and cross) to handle further web content. In this work we only focused on evaluating cursor variants on standard target acquisition tasks, but the following practical applications on the Web can be of interest for people with MIs.

The use of vertical drop down menus within navigation bars has been generalized on the Web, as these allow organizing and accessing the content of a website. However, interacting with these moving menus can be difficult for people with MIs. In this regard, the cross cursor was implemented to allow accessing navigation bars (Fig. 16), which involves handling with hidden and overlapping content, as well as the generation of appropriate shortcuts.

Selecting web forms elements such as radio buttons, check boxes or text boxes can also be challenging for people with MIs due to their small size. Although not all these web elements were implemented for this work, both virtual cursors (area and cross) could handle all them to assist access to web forms to people with MIs.

7. Conclusions and future work

The proposed virtual cursors (the cross and area cursors) proved to be beneficial for participants with MIs. Results obtained in the experimental sessions showed improvements in their performance when selecting links on web interfaces. Participants using a keyboard as an alternative pointing device (KU group), benefited from both virtual cursors to select links, although as expected, the best results were achieved with the cross cursor. On the other hand, users of specific alternative pointing devices such as the joystick or trackball (JU group), only benefited from the area cursor while the cross cursor was unanimously rated as the least preferred, behind the original cursor. These results are promising despite the limited number of participants in the study and support the idea that people with MIs need personalized adaptations in order to assist point and click interactions in GUIs, such as, for example, to access the Web.

However, considering the novelty of these virtual cursors for participants of the study and the duration of experimental sessions, we believe that with a longer learning period both groups of users with MIs would improve their performance. Therefore, we plan to conduct a longitudinal study, in which keyboard users on one hand and joystick and trackball users on the other, regularly perform point and click tasks with the cross and area cursor respectively, as well as with the original cursor. Besides analysing the learning effect on usage of each virtual cursor variant, we also seek to understand how the presence of distractor links around the target may influence performance (especially with the area cursor). It will also be valuable to see if participant satisfaction with virtual cursors declined or not over time. In addition, we will endeavour to recruit more participants in order to get more reliable insights.

Declaration of Competing Interest

None.

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