Understanding Pointing for Workspace Tasks on Large High-Resolution Displays

Lars Lischke[1], Valentin Schwind[2], Robin Schweigert[3], Paweł W. Woźniak[4], Niels Henze[2]

[1]Vrije Universiteit Amsterdam, the Netherlands,
[2]University of Regensburg, Regensburg, Germany,
[3]University of Stuttgart, Germany,
[4]Utrecht University, the Netherlands
[1]l.m.lischke@vu.nl, [2]firstname.lastname@ur.de, [3]robin.schweigert@gmail.com, [4]p.w.wozniak@uu.nl

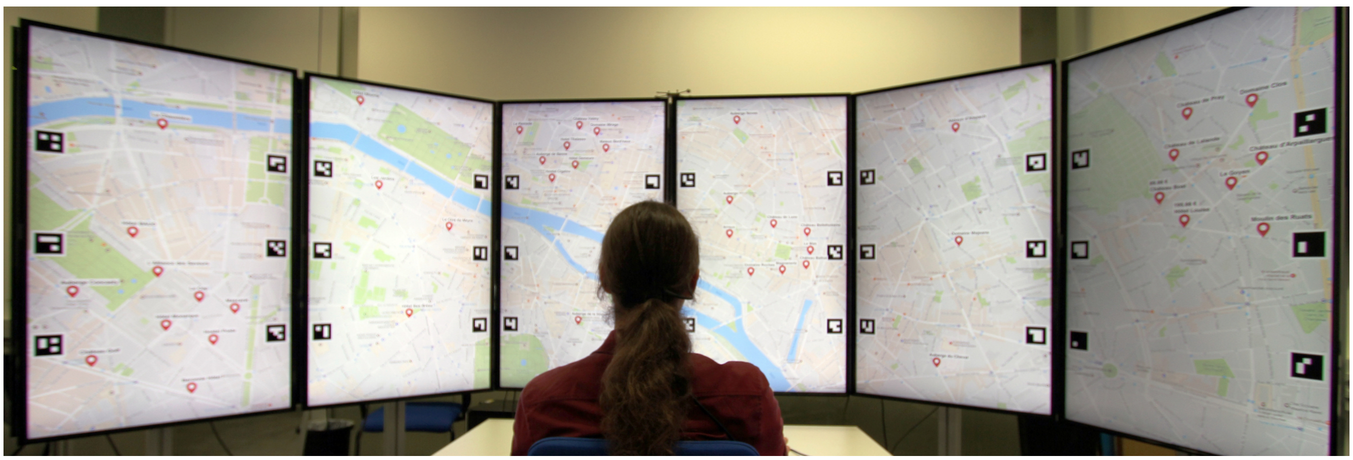

Figure 1: A user is performing the map based search task.

ABSTRACT

Navigating on large high-resolution displays (LHRDs) using devices built for traditional desktop computers can be strenuous and negatively impact user experience. As LHRDs transition to everyday use, new user-friendly interaction techniques need to be designed to capitalise on the potential offered by the abundant screen space on LHRDs. We conducted a study which compared mouse pointing and eye-tracker assisted pointing (MAGIC pointing) on LHRDs. In a controlled experiment with 35 participants, we investigated user performance in a one-dimensional pointing task and a map-based search task. We determined that MAGIC pointing had a lower throughput, but participants had the perception of higher performance. Our work contributes insights for the design of pointing techniques for LHRDs. The results indicate that the choice of technique is scenario-dependent which contrasts with desktop computers.

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CCS CONCEPTS

• **Human-centered computing** → **Displays and imagers**; Empirical studies in HCI.

KEYWORDS

Large High-Resolution Displays, Pointing, Eye-Tracking, MAGIC pointing.

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1 INTRODUCTION

Workspaces have always been populated with information. Walls full of post-it notes and flip charts are a common sight in many of today's offices. With the ever-decreasing cost of screen space, many predict that these traditional information media will be replaced by digital counterparts [36] to offer additional content flexibility and interaction opportunities. Furthermore, previous work has already identified manifold benefits of LHRDs [2, 6, 28, 34]. When LHRDs proliferate in everyday work environments, they will also need to begin support tasks now performed on desktop computers, e.g. working with spreadsheets. However, when working with an LHRD, pointing becomes challenging. First, because of the large interaction space, the cursor movement amplitude becomes very long. This increases the effort required for moving classical pointing devices, like the mouse or moving the fingers over a touch pad. Second, the large interaction space makes it hard for the user to follow and to rediscover the cursor [37]. Despite the fact that various research projects explored techniques to enhance pointing on LHRDs, e.g. through mid air gestures [32, 43], multiple cursors [23] or second device input [5, 31], none of these techniques are widely used.

Mouse and keyboard are the omnipresent input devices in office environments. Due to the deep familiarity with these devices for all users, they are unlikely to be replaced in office environments in the next decades. Consequently, in this paper, we look for input techniques which can be used in addition to traditional mouse and keyboard input for LHRDs. We aim to explore techniques that can be used in future work environments. Specifically, we investigate gaze-assisted pointing techniques and verify if manual and gaze input cascaded (MAGIC) pointing [48] (i.e. an interaction technique where the user can move the mouse cursor to their gaze point when clicking a mouse button) can be effective when applied to LHRDs. Past research has shown that, for some interaction scenarios, MAGIC pointing can significantly increase the effectiveness of pointing tasks [27]. We wondered whether that performance increase could be translated to the LHRD design space. To that end, we conducted a controlled experiment where participants completed a one-dimensional pointing task and explored map based data using MAGIC pointing and mouse and keyboard only. In the experiment, we observed that MAGIC pointing produced increased task completion time and error rate in the one-dimensional pointing task.

Our contribution is two-fold: (1) a systematic study of MAGIC pointing on an LHRD with a one-dimensional pointing task and a map-based practical task and (2) insights on the future applications of eye tracker-aided pointing techniques on LHRDs. This paper is organized as follows. First, we review past work on interacting with LHRDs and pointing using gaze data to highlight the need for our investigation. Next, we present the method used to study MAGIC pointing and we introduce the results of our experiments. Finally, we discuss our results and show how they can be used to design future pointing techniques.

2 RELATED WORK

The work presented, in this paper is inspired by previous work on gaze interaction and input techniques for LHRDs.

2.1 Gaze Assisted Pointing

For almost four decades research analysed the potential of eye tracking for interacting with computer systems. Bolt [4] proposed using eye gaze for interaction in 1982. Zhai et al. [48] proposed using eye gaze to move the cursor to the gaze position. The authors introduced two MAGIC pointing approaches. In one approach, they proposed to move the cursor constantly with the gaze point. In the second approach, the user was able to move the cursor to the gaze position by actuating the mouse. The authors compared both approaches with regular pointing using a computer mouse. The results indicated shorter target acquisition times when participants were able to move the mouse cursor to their gaze position on demand. Fares et al. [10] increased the target acquisition performance of MAGIC pointing through warping the cursor as soon as the user starts to move the mouse. To reduce the required time to trigger the demand for moving the cursor.

Drewes and Schmidt [8] proposed using a touch sensitive mouse for MAGIC pointing. Zhang and MacKenzie [49] compared three eye tracking based pointing techniques and mouse pointing using a standardized pointing task. The results showed that mouse pointing had the highest throughput. However, users also appreciated the eye tracking based techniques. Fono and Vertegaal [12] utilized the user's eye gaze to select windows and zoom selected images. The authors showed that participants were able to select windows significantly faster using eye gaze than with regular manual pointing. Further, Kumar et al. [25] explored combinations of keyboard and gaze input for target selection tasks. Serim and Jacucci [39] proposed enhancing touch input with non or little visual attention through gaze input. Jalaliniya et al. [21] showed that MAGIC pointing cannot only enhance interaction with desktop setups, but also with head-mounted display.

2.2 Input Techniques for LHRDs

Research has identified a performance increase when using larger display spaces and LHRDs for manifold tasks. For desktop tasks, productivity and satisfaction is increasing with increasing screen size [6, 14]. Ball et al. [2] showed that users perform a map-based visual search task faster on larger display space. Liu et al. [28] compared performing a classification task on an LHRD or on a regular desktop. The results revealed that users were able to classify information faster on an LHRD than on a regular display. Furthermore, Andrews et al. [1] showed that the extended display space supports the ability to organize information spatially in sensemaking tasks.

Despite the positive effect on performance and user satisfaction, performing input on LHRDs can be challenging [37]. For example, users easily lose track of the mouse cursor [37]. Nevertheless, in many LHRD setups mouse and keyboard are used as input devices [1, 20, 34]. To allow users to perform faster and still precise input, Esakia et al. [9] proposed using multiple acceleration curves. However, this does not support rediscovering the cursor.

A number of applications use direct touch for user input on LHRDs (e.g. [24, 33, 44]). However, direct touch as input technique requires that all areas of the display are easily reachable by the user [20]. Furthermore, interacting with the whole display space can be physically demanding [20].

In contrast to touch input, mid air pointing allows the user to keep the physical position and interact while standing or sitting. Haque et al. [15] proposed using pointing and clicking gestures detected by electromyography. Comparable to this, Wittorf and Jakobsen [46] present a full gesture set for interacting with LHRDs. Compared to direct touch, performing mid air gestures can be physically demanding.

Second device input has been explored in detail (e.g. [5, 26, 31, 45]). The advantage of smartphones and tablets as input devices is that they allow to present additional information and to change controls dynamically [45]. Furthermore, they are well-suited for collaboration [26]. However, even the ubiquity of smartphones increased the use of second devices as pointing device. Most proposed second device techniques, are tailor-made for specific applications and are not designed for general pointing tasks.

In contrast to other input techniques, the use of eye gaze for interaction with LHRDs is less explored. Stellmach and Dachselt [40] proposed two input techniques for remote displays using the eye gaze of the user to select an area on the screen and a smartphone for precise target selection. In line with these two techniques, Turner et al. [41] proposed using eye gaze and multi-touch to perform rotate, scale and translate task on remote displays. More recently, Voelker et al. [42] proposed combining direct touch with eye gaze interaction in multi display environments. Fortmann et al. [13] proposed supporting the cursor rediscover process by using eye gaze. Dickie et al. [7] showed that users can switch tasks faster in a multi display environment when the system moves the input focus to the screen where the user is looking at. In a lab study, Lischke et al. [27] compared MAGIC pointing to regular pointing with a standard mouse on a LHRD. The results of this study revealed an increase in pointing performance for long amplitudes. However, the improvement in target acquisition time was inconsistent over the display area.

3 METHOD

With MAGIC pointing, Zhai et al. [48] proposed to use eye gaze to reposition the cursor to support pointing tasks. Thereby, the gaze position is used in addition to the manual input performed using a mouse. Participants performed best when the cursor was not constantly moved to the gaze position, but positioned to the gaze position as soon as the mouse was actuated. To compare MAGIC pointing to classical manual pointing using a mouse on an LHRD, we implemented the MAGIC pointing technique comparable to this original technique and previous work [8, 27]: The eye tracker observes the eye movement of the participant continuously. As soon as the participant presses the right button on the mouse, the cursor is warped to the gaze position.

3.1 Study Design

We conducted a controlled laboratory experiment to build an understanding of the advantages of using MAGIC pointing when interacting with content displayed on an LHRD, focusing on the following research questions:

RQ1: Does MAGIC pointing enable more efficient pointing actions on LHRDs than mouse pointing?

RQ2: Is MAGIC pointing less demanding than traditional pointing with a mouse on LHRDs?

As we aimed to answer the two questions in a broad sense, the experiment used two tasks. First we employed a standard abstract one-dimensional pointing task, which emulated the task of the original Fitts' original experiment [11]. This task is commonly used to evaluate pointing performance (e.g. [19, 29, 49]). Secondly, we asked the participants to complete search task on a street map, inspired by Zhang et al. [50], to investigate a possible real-life scenario.

In both tasks, we used the input technique as independent variable with two levels: mouse only and MAGIC pointing. Implementing MAGIC pointing in a widely use manner and comparing this implementation to the most common pointing device in office environments, we achieve a study design, which allow produce comparable results [18]. We used a within-subjects study design. Hence, all participants performed trials with both input techniques. To balance learning effects, we altered the order of the conditions.

3.1.1 Tasks.

One-Dimensional Pointing Task:

To analyze the pointing performance, we used a one-dimensional pointing task, described by Sasangohar et al. [38] and ISO/TS 9241-411 [19]. We chose this because of the aspect ratio of the visual field of view and the aspect ratio (13:4) of the LHRD setup. During the pointing task, the study software showed two rectangular targets, which the participants were asked to select alternately. To indicate which target had to be selected, it was highlighted in red. As soon as the participant selected one target, the other one was highlighted. If the participant missed the target, the screen flashed red. Similarly to Sasangohar et al. [38], we used the target amplitude (A) as independent variable with four levels: 690, 1380, 2760, 5520 pixel. We also used the target width (W) as independent variable with four levels: 84, 169, 338, 675 pixel (1.12° (H), 2.32° (H), 4.64° (H), 9.20° (H)). Thereby, the index of difficulty ($ID = log_2 \frac{A}{W} + 1$) [30] for the easiest task was $ID = log_2 \frac{690}{675} + 1 = 1.02$ and for the hardest task $ID = log_2 \frac{5520}{84} + 1 = 6.06$. This is in line with the recommendations of ISO/TS 9241-411 [19], which propose using index difficulties between 1 and 6. Following the recommendations enable us to build a structured and comparable understanding of MAGIC on LHRDs.

Using two independent variables, each with four levels, and independent variable with two levels resulted in $4 \times 4 \times 2 = 32$ conditions. In every condition, participants performed 20 trials. The study instructor asked every participant to focus on accuracy, but also to perform the trails as fast as possible. Figure 2 shows a participant performing this task.

Map Based Search Task:

To analyze MAGIC pointing in the context of a task known to be effectively performed on an LHRD [2], we designed a visual search task inspired by Zhang et al. [50] and Ball et al. [3]. To understand if gaze visualisations support collaborative work, Zhang et al. [50] asked pairs of participants to discuss and select hotels for a assume city trip. Ball et al. [3] used map based exploration tasks, to show that participants acquiring insights faster on larger screen spaces. We presented each participant with a street map of Paris. We placed 43 map pins, indicating hotels. All hotels were located in clusters around four points of interest. The system showed the name and price of the hotel when the participant clicked on the pin. This information disappeared after two seconds. Each participant was asked to search for the cheapest hotel close to any of the places of interest. The task was completed after the participant entered the result into a text box and clicked on the button "done". By clustering the hotels around the places of interest and by requiring that the search target must be close to any point of interest, we created short and long distances between pointing targets. We asked the participants to search carefully and as fast as possible for the best option. In the study, we used two sets of hotels and places of interest, which we counterbalanced between the conditions. Figure 1 shows the map on

Figure 2: A participant is performing the one-dimensional pointing task.

the LHRD, while a participant is performing the task and analyzes hotel prices.

The map search task involves motor acquisition of the target and also requires the visual process of (re-) discovering the cursor as well as locating targets on a visually rich background. These visual search processes are challenging to perform on LHRDs [37]. To stimulate the need for rediscovering the cursor, we intentionally designed a task requiring not only pointing actions.

3.1.2 Measures. We measured the following depended variables during every study session:

Task completion time (TCT) [ms]. During the one-dimensional pointing task, we measured the time between the selection of the first target and the selection of the next target as TCT. During the map based search task, we measured the time between the map with the pins was rendered, and the participant indicated to have completed the task by pressing "done" as TCT.

Error rate (ER). [%] A missed target in the pointing task was counted as an error. The error rate is the ratio between the error count and the total number of trials.

Use of Eye Gaze warps. [number of warps] As an indicator of how often the participants used MAGIC Pointing, we counted how often participants performed gaze warps in conditions with MAGIC pointing.

Perceived Task load. [raw NASA TLX score] To assess the perceived effort for each task and condition, participants rated the effort on the raw NASA-Task Load Index (NASA-TLX) questionnaire [16, 17].

3.1.3 Apparatus. To conduct the study we used six Panasonic TX-50AXW804 screens with a resolution of 3840×2160 pixel and a diagonal of 50 in, aligned in portrait mode. This resulted in a 4.02×1.13 m display space, with a total resolution of $12,960 \times 3840$ pixel (approx. 90 PPI). To provide an equal viewing distance to the screens we aligned the screens in a semi-circle with a distance of 1.2 m to the participant. Thereby the display had a viewing angle of approximately 180° horizontal (H) and 42° vertical (V).

To realize MAGIC pointing we used a Pupil Labs headset [22] with a high-resolution (Full HD) world camera and binocular eye cameras running at a 120 Hz capture frequency. For calculating the gaze position, we used the Pupil Labs software, version 0.9.3 together with marker-based surface detection. We displayed the markers on the LHRD. This lowered the space between the single screens and enabled a more continuous image on the LHRD. We placed six markers per display for registering the 3D translation of the eye tracker.

One Microsoft Windows 10 workstation, with two Nvidia TITAN Pascal graphic cards drove the six 4K 50 in displays and the Pupil Labs eye tracker. The same machine ran the custom-made study software. We used only one workstation to minimize latency issues and ensure perfect timing.

In the middle of the display, at 1.2 m distance from the screen, we placed a chair for the participant. We placed a table with a standard office mouse and keyboard in front of the chair.

3.1.4 Participants. We recruited 35 participants (16 female, 21 male) aged between 19 and 31 ($M = 23.7$; $SD = 2.9$) by invitations over university mailing lists. Every participant received 10 EUR as compensation for taking part in the study. Because of technical challenges with the eye tracker with participants wearing glasses, participants were required to use contact lenses.

3.1.5 Procedure. After welcoming every participant, we asked them to read and sign the consent form. We invited them to take a seat in front of the LHRD and to fill in the demographics sheet. We explained the general purpose of the study and asked the participant to put on the eye tracker headset. When this was mounted, we calibrated the eye tracker using the Pupil Labs calibration routine and when completed the participant was given time to become familiar with the one-dimensional pointing task and the input technique. During this period, we asked participants to select targets with both input modalities. When the participant was ready, we started the trials with logging, alternating the order of the input technique used and randomizing the level of the other two independent variables. After performing all 640 target selections with one input modality, we asked the participant to answer the questions of the raw NASA-TLX and changed the level of the input technique to complete the abstract pointing task.

After completing the abstract pointing task, we continued with the map search task. We explained the task and showed an example map. Every participant could play around with the example map to get familiar with the functionality and the input technique. As in the abstract task, we altered the order of pointing techniques. When a participant reported that she or he understood the task, the actual experimental task was started. After entering the solution and pressing the ‘done’ button, we asked them to fill in the raw NASA-TLX questionnaire. Finally, we followed the same procedure with the second input technique.

4 RESULTS

During the study, the apparatus logged mouse clicks, cursor warps, when using MAGIC pointing and TCT. The perceived task load was measured using pen and paper. Based on this data, we conducted the following analyses.

4.1 Task completion time (TCT)

To analyse the TCT values for the one-dimensional pointing task, we used the TCT values logged by the apparatus. We removed trials with a TCT larger than 3 SDs, as outliers. We conducted a three-way repeated measures analysis of variance (RM-ANOVA) to analyse the effect of the independent variables on the TCT. Table 1 presents the results of the analysis. Tukey HSD post-hoc tests revealed that differences between the two experimental conditions were significant for all combinations of amplitude and width at the $p < .001$ level. Figure 6a shows the TCT per index of difficulty.

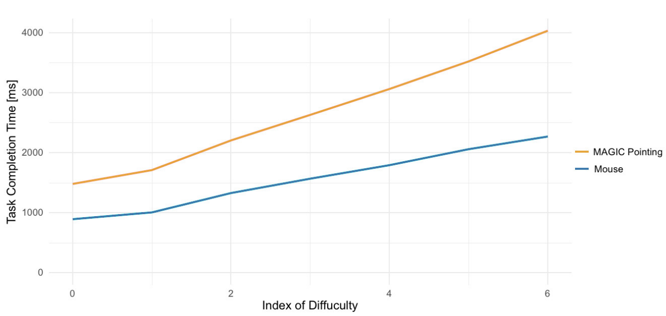


Figure 3: Task completion time (TCT) as a function of index of difficulty in the one-dimensional input task.

Furthermore, we compared the TCT for the map search task. The average TCT when participants used only the mouse as input technique was $M = 146.088$ s ($SD = 58.561$) and MAGIC pointing as input technique was $M = 143.873$ s ($SD = 75.276$). A one-way RM-ANOVA revealed no statistically significant effect of input technique on TCT, $p > .05$.

4.2 Throughput

Based on the TCT of the one dimensional pointing task, we calculated the throughput ($TP = \frac{ID}{MT}$ [bit/s]) [19]. Figure 4 shows TP per

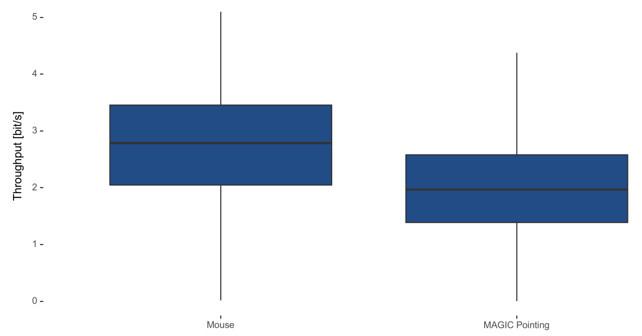


Figure 4: Throughput in the MAGIC pointing and mouse conditions. The result sis statistically significant.

target width (W), amplitude (A) and input technique. The MAGIC pointing had an overall mean TP of 1.93 bit/s. Input using only the mouse had an overall mean TP of 2.90 bit/s. A one-way RM-ANOVA revealed that there was a significant difference between the two experimental conditions, $F_{1,087} = 1729$, $p < .001$. Figure 4 shows differences in throughput between the two conditions.

4.3 Error rate

In the one-dimensional pointing task participants made on average $M = 0.028$ ($SD = 0.164$) errors when using MAGIC pointing. When participants used only the mouse, they made on average $M = 0.016$ ($SD = 0.126$) errors. For this task, we conducted a three-way RM-ANOVA to analyse the effect of the conditions on error rate. The results are presented in Table 1. Post-hoc analysis with Tukey HSD showed that differences between the two experimental conditions were significant for all combinations of amplitude and width at the $p < .001$ level.

4.4 Use of Eye Gaze warps

For the one-dimensional pointing and the Magic Pointing condition, how target width and amplitude affected the use of eye gaze warps by the participants (see Figure 5). We found a significant combined effect of target width × distance ($F_{9,153} = 4.13, p < 0.01$). Significant main effects were observed for target width ($F_{3,153} = 10.19, p < 0.01$) and amplitude ($F_{3,153} = 792.68, p < 0.01$).

4.5 Perceived Task Load

For the one-dimensional pointing task, a one-way RM-ANOVA for the combined scores of the raw NASA-TLX revealed no statistically significant difference between the two input techniques ($F_{1,34} = 0.096$, $p > .05$). Furthermore, we compared the responses for every item of the raw NASA-TLX. The statistical analysis revealed no significant differences for mental effort ($F_{1,34} = 2.9824$, $p > .05$), physical demand ($F_{1,34} = 2.984$, $p > .05$), temporal demand ($F_{1,34} = 2.566$, $p > .05$), effort ($F_{1,34} = 3.659$, $p > .05$) and frustration ($F_{1,34} = 0.273$, $p > .05$). However the statistical analysis revealed a significant effect on performance ($F_{1,34} = 6.215$, $p < .05$). Figure 6a shows NASA-TLX-scores. For the map based search task, the comparison also revealed no statistical significant difference

		TCT	Error
Amplitude	$F_{3,102}$	382.09 ***	0.15
Target Width	$F_{3,102}$	278.96 ***	5.68 **
Input Technique	$F_{1,34}$	155.49 ***	4.70 *
Amplitude × Target Width	$F_{9,306}$	1.44	0.72
Amplitude × Input Technique	$F_{3,102}$	15.77 ***	0.10
Target Width × Input Technique	$F_{2,102}$	0.97	1.81
Amplitude × Target Width × Input Technique	$F_{9,306}$	2.66 ***	0.74
Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 1 ' '			

Table 1: Three-way RMANOVA results for the pointing task

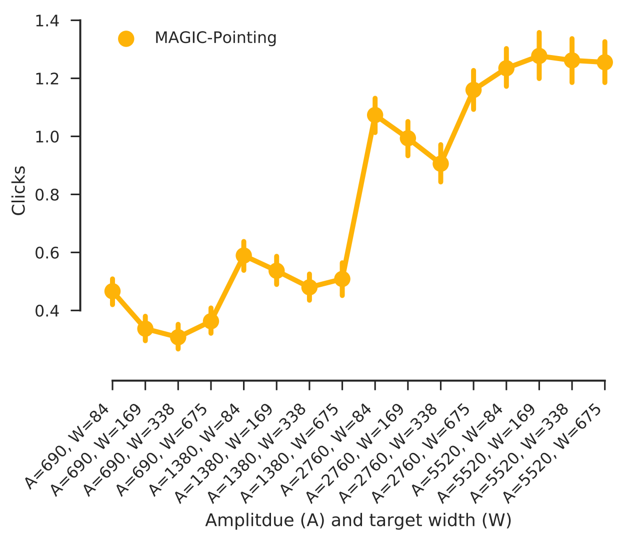


Figure 5: Number of gaze warps per condition in the one-dimensional pointing task. Bars show CI=95%. The X axis is order by index of difficulty.

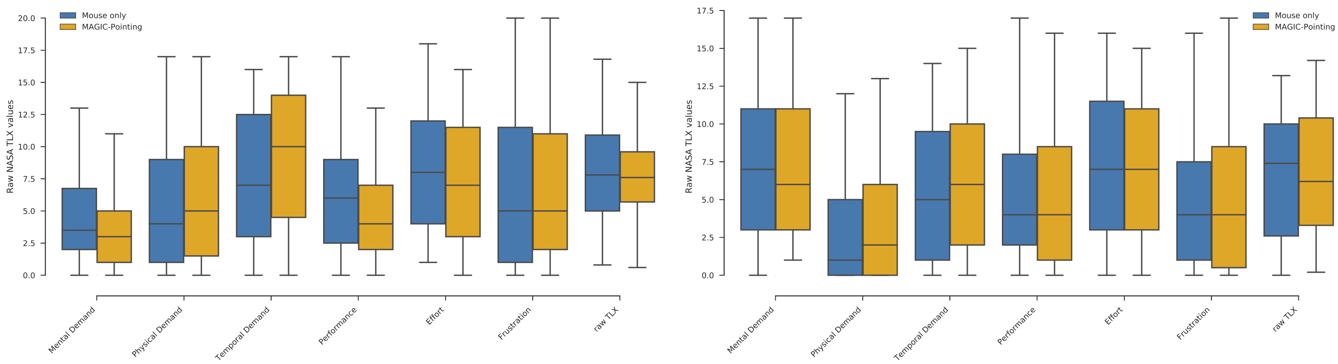
between the two input techniques ($F_{1,34} = 0.28$, $p = 0.6$). Also, the comparison of the single items revealed no statistical significant difference: mental demand ($F_{1,34} = 0.073$, $p = 0.788$), physical demand ($F_{1,34} = 1.434$, $p = 0.239$), temporal demand ($F_{1,34} = 1.609$, $p > .05$), performance ($F_{1,34} = 0.275$, $p > .05$), effort ($F_{1,34} = 0.335$, $p > .05$), frustration ($F_{1,34} = 0.263$, $p > .05$). Figure 6b shows the raw NASA-TLX-scores.

4.5.1 Qualitative Feedback. At the end of every study session, we conducted short semi-structured interviews with every participant. Overall, we recorded 92 min of interviews. The interviews underlined the quantitative results of the studies. Twelve participants mentioned they assumed they would have performed better with more precise gaze tracking. Also, six participants mentioned that they forgot to use MAGIC pointing because they were so familiar with using the mouse as a pointing device. However, twelve participants reported that they were able to perform the task faster with MAGIC pointing than with using the mouse only. Six mentioned that MAGIC pointing was, in particular, helpful for moving across long distances with the cursor. We concluded that overall, participants appreciated MAGIC pointing for the one dimensional pointing task. For the map based task, the participants had various opinions of the value of MAGIC pointing. While some claimed that the distances between the targets were too short to use MAGIC pointing, others argued that MAGIC pointing allowed them to focus more on the task. Instead of caring about the cursor position, the participants felt able to concentrate on the map and request the cursor to move to the visual focus area on demand. In line with this, seven participants explicitly mentioned this as an advantage and would also like to use their gaze point in other applications to reposition the system focus and the cursor position to the focused visual field.

5 DISCUSSION

In all conditions, MAGIC pointing did not outperform mouse only pointing. This is in contrast to the results of the original study presented by Zhai et al. [48]. Their results indicated shortest target acquisition time with MAGIC pointing, but due to the small number of participant could not show a significant effect. Furthermore, our results are in contrast to previous work presented by Lischke et al. [27]. The results of the lab study conducted by Lischke et al. [27] showed that MAGIC pointing decreased the target acquisition time, for targets which have a high distance to the cursor. However, the authors reported faster TCT not in all directions from the centre of the display.

On the other hand, the results of this study are in line with the results presented by Zhang and MacKenzie [49]. They used the two-dimensional pointing task, specified in ISO/TS 9241-411 [19]. This task is comparable to the one dimensional pointing task we used in this study. In both tasks, participants repeatedly pointed to targets on the same position. This eliminated the visual search of the target and allowed measuring only the motor movement time of the cursor. In contrast, Zhai et al. [48] and Lischke et al. [27], we used a random order of targets. This required locating the target visually, before moving the cursor to the target. Hence, the results of the one dimensional pointing tasks, show no benefit in terms of performance, when the position of the target is known by the participant. We did not observe a statistically significant difference in terms of target acquisition time in the map based search task. However, the descriptive statistics indicate an improvement in terms of TCT.



(a) Raw NASA TLX values for the one-dimensional pointing task.

(b) Raw NASA TLX values for the map based search task.

Figure 6: Perceived task load in both tasks measured with the raw NASA TLX.

Comparing the results of this work and the results presented by Zhang and MacKenzie [49] to the results of Zhai et al. [48] and Lischke et al. [27] showed that the question of an optimal pointing task to assess performance of pointing on LHRDs remains a research challenge. The results indicate, that MAGIC pointing supports pointing on targets which have an unknown position for the participant. If the participant knows the position of the target without looking at it, the hand motor performance for moving the mouse high and does not benefit from MAGIC pointing.

Interestingly, participants still used MAGIC pointing throughout the study, despite the fact that they perceived it as performing significantly worse. This indicated that there is a certain appeal to techniques based on eye tracking. As participants were eager to use MAGIC pointing as the distance between targets increased, we hypothesize that gaze warps were perceived as desirable when the distance to be travelled by the cursor was above a certain threshold. This is also indicated, by the increasing number of gaze warps with increased distance in the one-dimensional pointing task. In conditions with the largest amplitude (A=5520), participants used, on average, more than one gaze warp per trial. This indicates the high desire to use MAGIC pointing for large amplitudes. However, this also shows an high inaccuracy in this condition. In practical tasks, this threshold maybe determined by the maximum distance that can be performed without clutching or a distance that does not require head rotations. In this context, we can attribute the inferior performance in the one-dimensional pointing task to the the fact that tracking head rotation precisely in a multiscreen environment may have been not accurate enough. As participants were more incline to use gaze warps with pointing distances requiring excessive head rotation, they also used gaze warps in cases where the eye tracker can offer the least accuracy.

We have extended past work and shown that MAGIC pointing does not offer a performance benefit when visual search is not part of the task, even for LHRDs. However, our results also indicate that participants were eager to use gaze warps above a distance threshold. As we observed no difference in performance in the map based search task (i.e. a task that required visual search), we hypothesise that MAGIC pointing may be beneficial for search tasks on LHRDs. While we were unable to show that the benefits of eye tracking for visual search (e.g such as those presented by Zhang et al. [50]) are also true in an LHRD scale, our results indicate that this is possible. Given that the one-dimensional task showed that an increased tracking accurate was required, we expect that superior performance for visual search tasks can be achieved if better head tracking is available. However, technical innovation is required to verify this hypothesis in a future study.

Future work should address the question how MAGIC pointing supports target acquisition beyond the pure motor task of a pointing task. Here, we showed, in connection with previous work [27], that MAGIC pointing is beneficial when the visual search task involved in the pointing task is demanding. MAGIC pointing seems to be promising in multidisplay environments, as such environments commonly increase the effort of visual attention due to switching the focused display area [35]. The large size and the high resolution of such displays, causes already for small index difficulties long target acquisition times. However, in contrast, even high index difficulties would be realistic for LHRDs. To understand fully how MAGIC pointing on LHRDs influences participants' performance, user studies with wider ranges of index difficulties need to be performed. Furthermore, combining MAGIC pointing with other input techniques than mouse pointing seems to be valuable. Here it could be interesting to continue work on combining eye gaze interaction with mid air gestures (e.g. [47]).

In summary, our work shows that **MAGIC pointing can offer little benefit to interaction for repetitive tasks, where participants know exactly where to click on an LHRD.** Thus, we see that eye tracking support for such tasks should be avoided in future systems. As we observed that performance was not affected in the visual search tasks, we believe that users may welcome MAGIC pointing as a beneficial feature in such scenarios. Consequently, we believe **that gaze-supported pointing techniques for visual search tasks should be used with LHRDs.** Our work also indicated that tracking head rotation for LHRDs is still a challenge and may result in accuracy issues. Consequently, improving head tracking methods for gaze on LHRDs is an important challenge for future work. Lastly, we see that participants were willing to use MAGIC pointing through our 60 min long study, especially in the map based search tasks. This was despite the fact that they were free to not use gaze warps. As a consequence, we recognise that there is a certain appeal and a perceived benefit of MAGIC pointing that goes beyond novelty and the technique should be further refined for LHRDs.

6 CONCLUSION

In this paper, we investigated if users working on LHRDs can benefit from MAGIC pointing. We conducted a study where users completed an abstract one-dimensional pointing task and a map search task. We found that MAGIC pointing offered inferior performance in the pointing task and there was no performance difference in the map based search task. Users were more likely to use gaze warps for larger pointing distances. Our results indicate that MAGIC pointing is an appealing pointing technique for visual search tasks, but it may cause issues when performing common tasks when the user knows exactly where to point next.

Our work deepens the understanding of MAGIC pointing and shows the intricacies of interacting with LHRDs. The results presented pose challenges in terms of testing LHRD performance in further visual search tasks. We hope that this paper will inspire further research on how to manage and interact with abundant screen space. Finding new ways to interact with large screens will enable users to truly benefit from the anticipated advantages of LHRDs.

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