Exploring Discrete Drawing Guides to Assist Users in Accurate Mid-air Sketching in VR

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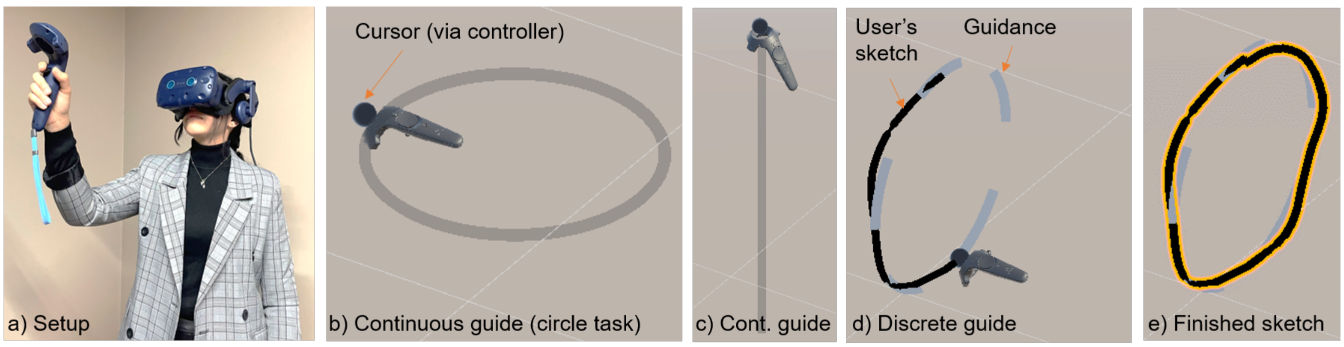

Figure 1: Current Virtual Reality (VR) design applications support immersive sketching through mid-air drawing with a hand-held controller (a). We study how users draw basic sketch primitives, when assisted in their sketching task through continuous (b-c) and discrete (d-e) guide designs that allow tracing accurate shapes.

ABSTRACT

Even though VR design applications that support sketching are popular, sketching accurately in mid-air is challenging for users. In this paper, we explore discrete visual guides that assist users' stroke accuracy and drawing experience inside the virtual environment. We also present an eye-tracking study that compares continuous, discrete, and no guide in a basic drawing task. Our experiment asks participants to draw a circle and a line using three different guide types, three different sizes and two different orientations. Results indicate that discrete guides are more user-friendly than continuous guides, as the majority of participants preferred their use, while we found no difference in speed/accuracy compared to continuous guides. Potentially, this can be attributed to distinct eye-gaze strategies, as discrete guides led users to shift their eyes more frequently between guide points and the drawing cursor. Our insights are useful for practitioners and researchers in 3D sketching, as they are a first step to inform future design applications of how visual guides inside the virtual environment affect visual behaviour and how eye-gaze can become a tool to assist sketching.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Virtual reality**.

KEYWORDS

3D sketching, Eye-Gaze, User Study, VR, Guides

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1 INTRODUCTION

Current VR systems have made 3D sketching available to artists, engineers, and designers. 3D sketching transforms design activities

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as it is a new medium that provides designers with the expressiveness, immediacy and editability of traditional 2D sketching. It also supports body-centered spatial awareness, presence, and multiple perspectives afforded by traditional 3D design tools, such as prototyping [1]. 3D sketching also decreases the workload on the task, as depicting complex shapes in 2D drawing requires multiple sketches from different viewpoints [32]. However, 3D sketching is less accurate than 2D ones [3]. Several researchers have investigated the use of visual guides to aid the user in drawing accurate shapes in 3D space [7, 18, 39]. While visual guides are understood to improve the user's shape accuracy [7], they need to be carefully designed to avoid potential detrimental effects on user stroke performance. For example, extra visual cues in the canvas can detract a person's attention away and influence how one normally coordinates the pen with the drawing output, e.g., in Arora et al.'s [3] study on drawing 2D curves in VR, they found that tracing virtual objects through pre-defined visual guides can render the user's stroke less accurate than a free sketching approach. Despite these conflicting results, few works have explored how changing the visual aspect of a pre-defined guide affects a person's stroke performance.

To better understand the human factors underlying the application of visual guides, we aim to extend the empirical knowledge in this line of research through two novel aspects. First, we propose the use of a hybrid, segmented visual guide design called *"discrete visual guide"* (Figure 1-d, e) as a visual guide inside the virtual environment. It strikes a balance between providing visual assistance for shape accuracy while leaving part of it to free sketching. Potential advantages include 1) to alleviate the inaccuracy issues of full guides [3], 2) offer a less occluded field of view by the partial visualisation, and with it 3) contribute to a positive effect on the user's experience. Second, we also extend the prior art through analyzing the eye-gaze behaviour of our participants while drawing with different visual guides. This is a novel aspect in our methodology that has the potential to provide a more detailed view of the visual guides effect on the user's 3D sketching performance, as most work around eye-gaze behaviours is for 2D drawing. In particular, use of discrete guide can trigger eye-hand coordination different from the natural tracing and drawing behaviours [17].

The appropriation of human gaze behaviour analysis set in context of manual tasks has been vital in various VR research efforts, such as eye-hand coordination training [28], behavioural biometrics [29], and menu interaction design [31]. We offer insights into eye movement behaviour during 3D sketching, a task where eye-hand coordination is critical to the user's performance. Especially with different visual guide designs – that directly affect where a user gazes upon. Insights into this could be helpful in future VR sketching systems, 1) to inform the application and design of visual guides, but as well 2) to design novel forms of design assistance that analyses gaze behaviour and adapts intelligently to the current user's situation.

In this paper, we explore how different visual guides (discrete, continuous, and no guide) given different task properties (object shape, size, and orientation) affect the user's accuracy, performance, and visual attention. Here, we define a *continuous guide* as the visual design cues always visible to the user while drawing the shape, as shown in Figure 1(b,c). A *discrete guide*, on the other hand, has visual cues segmented through the design guide, as shown in Figure 1(d). In the *no guide* condition, guide is visible to the users before they start sketching, but not while sketching. In a user study, users drew lines and circles using VR controllers. From this study, we have drawn several insights. First, we find that both continuous and discrete visual guides improve the user's accuracy at the compromise of slower task completion (compared to no guide). While we found no differences in accuracy/time between both visual guides, the majority of participants prefer the discrete guide. Secondly, our gaze data analysis provides a better understanding of how visual guides affect eye-hand coordination while 3D sketching. With the continuous guide, the eyes were more often fixated closely to the pen cursor, whereas the discrete guide led to the eyes more frequently switching between fixating at the cursor vs. fixating at the guideline.

Our contributions include insights into visual guide designs and the user's eye-hand coordination during mid-air sketching. We also experimentally evaluated various important sketching task parameters that are frequently used in 3D sketching applications. We consider our work beneficial for practitioners and researchers in this domain, as we expand the empirical knowledge on spatial sketching, and as a point of departure to consider future design assistance tools that can potentially integrate the gaze behaviour for more intelligent, context-aware assistance to the user.

2 RELATED WORK

Sketching in VR or 3D Sketching, uses a six degree of freedom (6-DOF) input device to create strokes by following the user's hand movements. This technique is called freehand drawing and is flexible and fast [36]. Users are also immersed inside the drawing and can sketch directly in 3D space [20] while 3D sketching. Despite these advantages, correctly positioning a stroke in 3D space difficult as users are affected by high sensorimotor [37] and cognitive [8] demands, the depth perception issues associated with stereo displays [6, 9, 10], and the absence of physical support [3]. Previous work has studied the control and ergonomic issues of sketching in mid-air [3, 24] and the learnability issues of 3D sketching [8, 37] to identify the cause of this inaccuracy. Other works have made different attempts to improve user accuracy while sketching in virtual environments, including beautification [5, 16], surface snapping [2, 5, 25] the use of novel metaphors to create strokes [21, 22] and using haptic feedback to show the position of the drawing surface [14]. In this work, we evaluate the difference between using difference visual guides on user performance and on their eye-gaze behaviours.

Previous work has analyzed users' eye-gaze behaviours when performing creative tasks in the domain of 2D drawing. For example, Sun et al. [34] recorded participants' eye movements to analyze their perception of their sketch, and to identify how designers create new ideas. When looking at the user's behaviour when drawing 2D shapes, users exhibit distinct eye-hand coordination movements. For example, there is eye pursuit behaviour where the user closely follows the hand with their eyes and eye anticipating behaviour where the eyes look ahead to future hand targets [35]. Users also use specific eye scan paths, where they focus only on the parts of the object they are drawing, and they follow a scan path that resembles an edge-following pattern along image contours [12]. Finally, there are differences in the eye movement characteristics between tracing and drawing, as tracing demands continual comparison between the line to be traced and pen tip [17]. Our study contributes to this space, as we explore gaze strategies for 3D sketching in different tracing tasks. Other work focuses on understanding how the user's eye-gaze behaviour affects their drawing accuracy [13]. For example, Cohen [13] identified that high gaze frequencies may facilitate drawing accuracy. He identified three advantages, first users can hold less information in memory, second, there is a reduced memory distortion, and third, there is a reduction of context effects through inattentional blindness.

Our work focuses on understanding visual attention during sketching, that can be considered as a basis to inform how more interactive gaze techniques can be integrated into VR design applications. Research in eye-gaze as an input in VR interfaces shows that it allows users to take advantage of faster actions for various tasks [11], requiring less muscle movement and therefore energy [33]. For example, human gaze movement speed can reach up to 900 degrees/s [4], which could be used as a fast input method in VR systems. These characteristics of eye-gaze provide novel opportunities to consider gaze-responsive design techniques. Jowers et al. [23], for instance, use gaze to identify the user's intention when creating a new shape. In VR, multimodal eye gaze and gestural user interfaces can provide novel interaction styles that advance the user's manual input capabilities [30]. Especially for the use case of design and sketching in VR, researchers proposed to assist the user in gaze-based mode switching during sketching to allow users to leave the pen at their comfort position [31], or proposed to directly apply parameters to objects by a gaze-based see-through tool [27]. Our work provides empirical knowledge on natural gaze behaviour during sketching tasks, and it could be useful as a basis for further research on gaze-interactive design applications.

3 USER STUDY

Our experiment investigates discrete visual guides for mid-air sketching in VR, by comparing them to continuous guides and to a free sketching baseline without any visual guide, i.e., no guide condition. Our research questions are:

- *(RQ1)* How do different visual guides designs affect the user's sketching performance and accuracy? This question verifies prior work's findings for 2D drawing [17] and 3D drawing [3] that found a difference in accuracy between drawing and tracing. This question also sets the basis for the subsequent questions on eye-tracking analysis.
- *(RQ2)* How do the visual guides design affect the user's gaze behaviour? We inspect eye-hand coordination to understand the interplay between the two modalities. Particularly, we regard fixations for gaze behaviour and visual angle between eye and hand rays for indication on eye-hand coordination.

3.1 Participants

We recruited eighteen participants (7 female, 11 male) aged between 18 and 21 years (M = 19.8, SD = 1.97). Participation in our experiment was voluntary, and no compensation was offered. All participants were from the local university. Fourteen participants have no drawing background, three participants draw 1-2 hours in a week, and one participant draws 6-10 hours in a week including AutoCAD. None of the participants had experience with VR sketching.

3.2 Apparatus

We conducted the experiment on an 11th Gen Intel(R) Core(TM) i7-11700F core 2.5 GHz, 32 GB RAM desktop PC with an NVIDIA GeForce GTX 3070 graphics card. We used an HTC VIVE Pro Eye headset with their controllers. We provided participants with a 4 m x 4 m drawing area free of obstacles. For the virtual environment, we used Unity version 2020.3.21f1. It consisted of open space with no spatial reference except for a ground plane and the virtual surface that displays the current shape. The surface location was centered in the physical space available to our users, and its position remained constant throughout the experiment.

3.3 Procedure

First, we instructed our participants about the experiment. Then the participants tested the VR system. They were left free to draw anything and explore the VR environment. After that, we asked them to draw actual shapes in the experiment until they were comfortable with their usage. Additionally, participants filled the demographics part of the survey. Before starting the experiment, we calibrated the eye tracking for each individual. In the experiment, we asked participants to draw thirty-six sketches (2 shapes, 3 guides, 2 directions, and 3 sizes). All participants followed the same procedure while drawing. Participants drew the circle counterclockwise starting from the top of the guide. Participants drew the line from top to bottom in the lateral direction, and from the closest point to them for the depth direction. For the *continuous guide* and *discrete guide* conditions, participants followed the visual guide while drawing. For the *no guide* condition, we first showed them the drawn shape as a continuous-guide, and only after the participants started drawing, the guide disappeared. After the experiment was over, we asked the participants to fill the second part of the survey to identify the visual guide they preferred and why.

3.4 Task

The task was for participants to draw two simple geometrical shapes, a planar circle and a planar line in three sizes (10, 60, 110 cm). Each shape can be in two positions: depth (drawing plane is parallel to the user's view direction) and lateral (drawing plane is perpendicular to the user's view direction). See Figure 1 for an example of the different drawing conditions. Participants were not allowed to discard input sketch while the experiment was in progress.

3.5 Experimental Design

We used a four-factor within-subjects design with three **visual guides** (3_{VG} = no visual guide, continues visual guide and discrete visual guide), two **object shapes** (2_{OS} = line and circle), three object **sizes** (3_S = small - 10 cm, medium - 60 cm and large - 110 cm) and two object **alignment** 2_A = depth and lateral) conditions, comprising a $3_{VG}\times 2_{OS}\times 3_S\times 2_A$ design. Each participant completed one sketch for each condition, for a total of 648 recorded trials over all participants. The order of conditions was randomly assigned for each participant.

Table 1: One-Way RM ANOVA results of Within Subjects Design

	Elapsed time	Average distance from the guide	Standart deviation of distance from the guide	Cursor fixation	Average degree between cursor and gaze
Visual Guide	F(2, 34)=75.316, p<0.001, η^2= 0.816	F(2, 34)=40.962, p<0.001, η^2 =0.707	F(2, 34)=70.429, p<0.001, η^2= 0.806	F(2, 34)=7.134, p<0.01, η^2 =0.296	F(2, 34)=6.711, p<0.01, η^2 =0.283
Object Shape	F(1, 17)=552.238, p<0.001, η^2= 0.970	F(1, 17)=5.922, p<0.05, η^2=0.258	F(1, 17)=15.458, p<0.001, η^2= 0.476	F(1, 17)=99.803, p<0.001, η^2=0.854	F(1, 17)=99.803, p<0.001, η^2=0.854
Size	F(2, 34)=564.348, p<0.001, η^2= 0.971	F(2, 34)=16.409, p<0.001, η^2= 0.491	F(2, 34)=135.330, p<0.001, η^2 =0.888	F(2, 34)=16.918, p<0.001, η^2=0.499	F(2, 34)=100.74, p<0.001, η^2=0.856
Alignment	F(1, 17)=38.125, p<0.001, η^2= 0.692	F(1, 17)=25.946, p<0.001, η^2 = 0.604	F(1, 17)=0.096, p=0.761, η^2=0.006	F(1, 17)=4.914, p<0.05, η^2=0.224	F(1, 17)=28.363, p<0.001, η^2=0.625

3.6 Evaluation Metrics

For performance measures, we logged drawing time (s), the average distance from the guide (cm), the standard deviation of the average distance from the target line (cm). We measured the drawing time to analyze the speed-accuracy trade-off between different guides. The drawing time measurement starts when users begin sketching (controller button pressed) and ends when the line is finished (button released). For the average distance from the guide measurement, we started to log the distance between the cursor and the closest point to the guide when the controller button pressed and stopped at the end of button release. Then, we averaged all the calculations. For the the standard deviation of the average distance from the target line, the calculated the standard deviation of the logged distances. Regarding eye-tracking data, we measure gaze fixations, e.g., how many times the participant fixed their eye-gaze in the cursor and eye-hand coordination indicators. We also calculated normalized gaze fixations on the controller's cursor by dividing the number of cursor fixations on the cursor with the elapsed time. This allowed us to eliminate the impact of the task execution time on the number of fixations. For the eye-hand coordination, we collected the degrees of visual angle between the gaze direction ray and the ray formed from the user's head position to the cursor position of the controller, which represents how close users are looking to their hands.

4 RESULTS

We used Skewness (S) and Kurtosis (K) for normality analysis and considered data as normally distributed when the S and K values were within ± 1.5 [19, 26]. However, none of the data was normally distributed even after the log-transformation, so we used ART [38] for each dependent variable. After ART, the data for this user study were analyzed using Repeated Measures (RM) ANOVA in SPSS 24. We only report significant results for *brevity*, including for interaction results. Results are illustrated as means and standard error of means in figures. See Table 1 for the results.

Time. We calculated the average drawing time for each condition in our experiment. Our results show that people drew faster without visual guides than with discrete and continuous guides (Figure 2(a)). We also found that our participants drew lines faster than circles (Figure 2(b)), and smaller shapes faster than larger shapes (Figure 2(c)). Finally, we identified that our participants drew faster on the lateral plane than the depth plane ((Figure 2(d)).

User Accuracy. We calculated the average distance from the guide to evaluate the user's shape likeness accuracy, e.g., how similar is their drawing with respect to the example. We also calculated the standard deviation of the average distance from the guide to evaluate the user's line precision, e.g., how straight the line is. We found that our participants drew better with discrete and continuous guides than without guides for shape likeness (Figure 2(e)) and line precision (Figure 2(i)). We also found that our participants were more accurate when drawing a line than a circle (Figures 2(f) and 2(j)), and when drawing smaller shapes (Figures 2(g) and 2(k)). Finally, for shape likeness, we found that when drawing in depth planes, our participants were more accurate than when drawing in lateral planes (Figure 2(h)) .

Gaze Behaviour. We also assessed whether the visual guide affected the eye-hand angle. For fixations, the results showed that participants looked more to the cursor with continuous guides compared to the no guide condition (Figure 2(l)). Similarly, when looking at the angle, the results showed that participants looked closer to their hands with the no guide condition in terms of angles than the continuous guide and looked closer to their hands with the discrete guide than the continuous guide (Figure 2(p)). We also found that the size of an object could potentially affect the user's eye behaviour. One-Way interaction results showed that participants looked more times at larger objects compared to medium and small object sizes, as shown in Figures 2(n) and 2(r). To explore this impact further, we analyzed the interaction effect between visual guide and target size. However, we did not observe any significant difference between the target size and the visual guide (F(4,68)=0.286 p=0.886 η^2= 0.017). Finally, for drawing direction, we found that our participants looked more at the guides when drawing in the depth direction than the lateral direction.

Questionnaire Results. Two participants preferred *no Guide*, two *continuous guide* and the rest *discrete guide*. The participants who preferred *no Guide* commented ".. easy to draw from imagination" and "focused more on drawing." Participants who preferred *continuous guide* commented "I lost my depth perception with other guides" and "familiarity with continuous guides". The other fourteen participants who preferred *discrete Guide* commented "easy to follow", "easy to steer and "easy to draw", "perceived depth better". We also asked if it was easy to draw with each guide (1- completely disagree, 7- completely agree). Participants neither agreed nor disagree that it was easy to draw with *no Guide* (μ) =4, average (AVG)=3.94, standard deviation (SD)= 1.43, agreed that it was easy to draw with *continuous guide* (μ) =6, AVG=5.64, SD= 1.05 and agreed that it was easy to draw with *discrete guide* μ=6, AVG=6.1, SD=0.85.

5 DISCUSSION

We discuss the main insights that we gained through our experiment to answer our research questions.

Visual Guide vs. No Visual Guide. The main comparison is on the addition of visual guides in contrast to free drawing of the shape. Our findings confirm prior work [3] that the addition of a visual guide provides a distinct speed-accuracy trade-off. With both types of visual guide (continuous and discrete), users were more accurate at the expense of time. User acceptance, however, does not always correlate with the actual performance. In the tested line and circular tasks, we find that users clearly prefer to draw with visual guides.

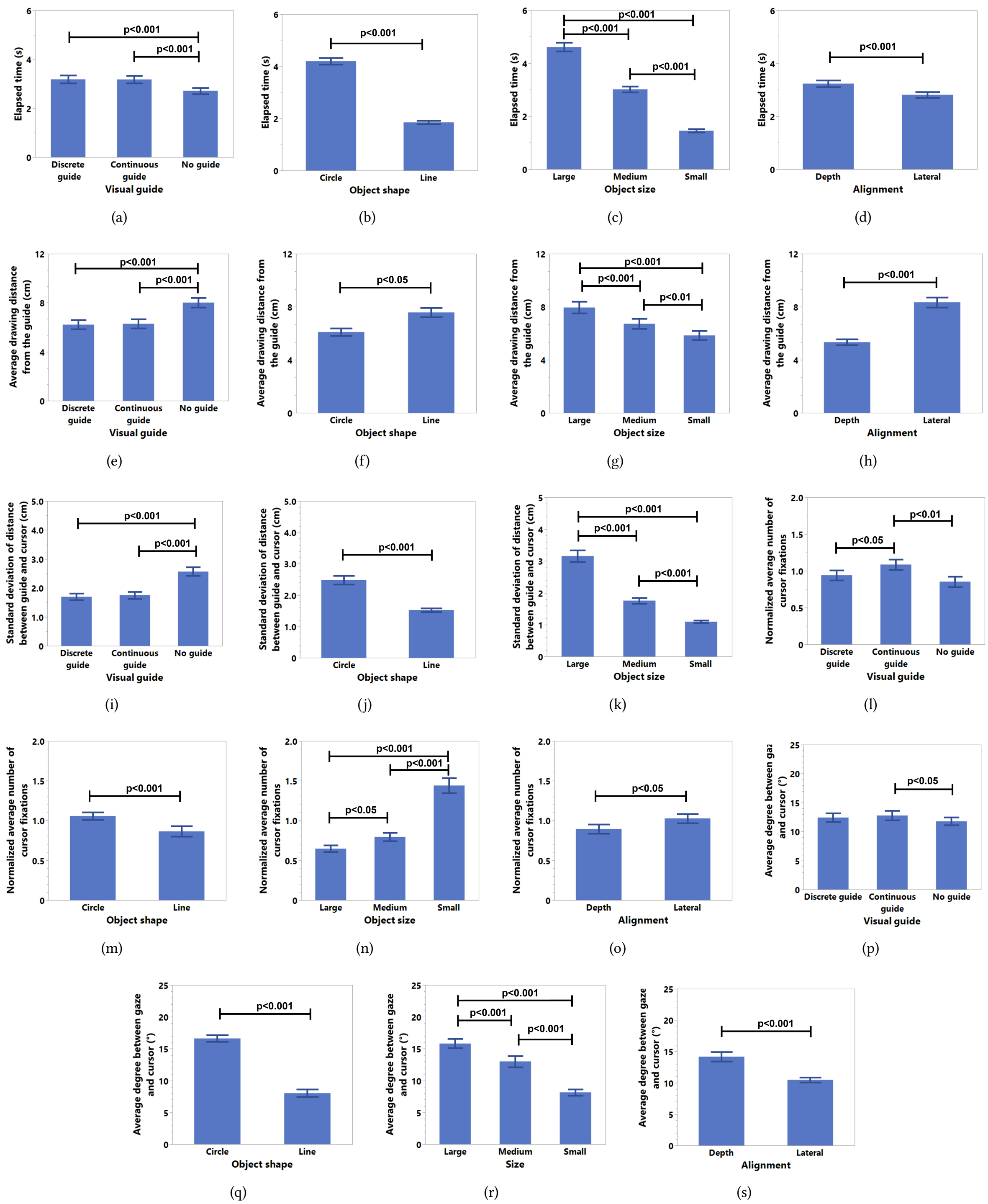

Figure 2: Detailed time results for (a) visual guide, (b) object shape, (c) object size and (d) object alignment. Detailed average drawing distance for (e) visual guide, (f) object shape, (g) object size and (h) object alignment. Detailed standard deviation of distance between guide and cursor results for (i) visual guide, (j) object shape and (k) object size. Detailed normalized average number of cursor fixation results for (l) visual guide, (m) object shape, (n) object size and (o) object alignment. Detailed normalized average number of cursor fixation results for (p) visual guide, (q) object shape, (r) object size and (s) object alignment. Error bars represent the standard error of the mean.

Discrete vs. Continuous Visual Guides. A novel aspect of our study is that we include discrete guide, as a middle ground between full assistance and free sketching. Counter to our expectation, we did not find any effect on drawing accuracy or completion time compared to using the continuous guide. The user feedback, in contrast, showed a clear preference toward the discrete guides – users noted it facilitates depth perception, is easier to follow and steer by hand.

Overall, the results on time and accuracy showed that there is a speed-accuracy trade-off between different visual guides; participants were faster with the No Visual Guide condition while they were less accurate, which answers our research questions how different visual guides designs affect the user's sketching performance and accuracy *RQ2.*

Eye-hand Coordination. Previous work on 2D drawing [35] identified that users follow an eye pursuit behaviour. Our results sustain this work, as for all conditions we identified that users fixate at their cursors, but also at their hands represented by the degrees between their gaze and the cursor. Other work on 2D drawing, identified that a high gaze frequencies, high fixations and high angle, may facilitate drawing accuracy [13]. Our results could not verify this, as for the drawing direction and the size conditions, users drew more accurate when looking at the visual guide more (high fixations and low angle). The drawing shape also shows an interesting result, as participants were more accurate when drawing a line, even if they had lower fixations and lower angle. These results show us the need to continue researching eye-gaze behaviours when 3D sketching.

The analysis on the user's visual behaviour during sketching tasks was insightful in characterising the guide conditions in more detail. In principle, the continuous guide led to users fixating the drawing cursor more often, whereas the discrete guide led to users switching between fixating on drawing cursor, and the visual cues of the guide. Thus, the discrete guide fragments made users rely less on the visual cue, e.g., these guides break the eye-hand coordination into the different parts of the sketch task, which also answers our research question on how do visual guides design affect the user's gaze behaviour *RQ2.* Although no effect was found for accuracy/speed in 3D drawing, we attribute the differences in user preference to the task's division of labour into smaller sub-tasks of lower coordination complexity, relating to a change of cognitive load. We also speculate that this is why also participants preferred the discrete visual guide.In our data analysis, we did not observe any significant interactions between object shape and visual guide which also motivates us to hypothesize that our results are not impacted by the shape complexity.

Depth vs. Lateral Direction. We note that across the tasks, there is a speed-accuracy trade-off between two drawing directions. We expected depth drawing (i.e., for-/backward direction from the user's perspective) to be less precise as there is a higher potential of occluding the own view by the hand. Also, previous work [3] found that drawing in depth is worse than lateral. Yet, our results show that drawing into depth from a user's perspective is slower, but it leads to higher shape accuracy.

6 CONCLUSION

In this paper, we investigated discrete visual guides to assist the users during mid-air sketching in VR. In our findings, we did not observe any significant difference between continuous and discrete guides in terms of speed and accuracy, but participants preferred the discrete guides. We also found out that the eyes of the participants were focusing more frequently on the cursor with the discrete guide, which contributes to reducing the task complexity and with it potentially the cognitive load during the sketching. Our work stands as a basis for the integration of eye-tracking into immersive design applications, and we believe that understanding and enhancing the user's eye-hand coordination can lead to mitigating some of the issues of spatial sketching, while potentially unveiling new interactive designs to assist users when they sketch with visual helpers. For example, if the eyes reveal that users do not follow the typical behaviour of shifting between visual guide points and cursor, it provides cues to the system that the visual guide might not be ideal and could be adapted. Another more direct method would be, when users anticipate a drawing destination with their eyes, to adaptively reveal visual guide points to the user in that direction. The results here can be applied to 3D sketching applications, training systems, computer aided design, and can be used by practitioners, developers and designers. In the future, we want to utilize our findings and explore such visual guide possibilities that incorporate gaze movements in intelligent ways to facilitate 3D sketching. We also aim to expand the empirical knowledge in this domain, such as by quantitative analysis of the questionnaire results, studying the eye-gaze behaviours of people with different demographics, with different design expertise, and different device constellations such as freehand drawing and AR graffiti, where the real world represents further visual anchor points. Finally, we aim to explore other uses for the proposed visual guides, like helping people remember hand gestures for VR interactions by tracing them [15].

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