Comparing Input Modalities for Shape Drawing Tasks

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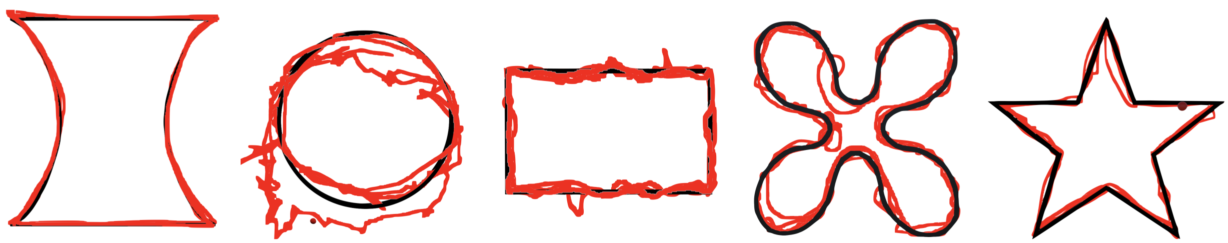

Figure 1: Superimposed drawings of the first study group, which indicate the drawing accuracy for each input modality.

ABSTRACT

With the growing interest in Immersive Analytics, there is also a need for novel and suitable input modalities for such applications. We explore eye tracking, head tracking, hand motion tracking, and data gloves as input methods for a 2D tracing task and compare them to touch input as a baseline in an exploratory user study (N=20). We compare these methods in terms of user experience, workload, accuracy, and time required for input. The results show that the input method has a significant influence on these measured variables. While touch input surpasses all other input methods in terms of user experience, workload, and accuracy, eye tracking shows promise in respect of the input time. The results form a starting point for future research investigating input methods.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Empirical studies in interaction design**; **Empirical studies in visualization**.

KEYWORDS

Immersive analytics, input modalities, interaction

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1 INTRODUCTION

The fields of Visualization and Human-Computer Interaction (HCI) are influenced by the increasing importance of Virtual and Augmented Reality (VR/AR). This trend also led to the development of alternative input modalities beyond mouse and keyboard that enable natural interaction in VR and AR. A very common task in visualization interfaces is selection, which often requires to draw shapes to single out certain data regions. For this task one could use touch screens, gaze interaction, mid air gestures, or even the movement of body parts like the head. However, each input method has its own benefits and drawbacks, and no input method is perfect for all tasks, thus an exploration of trade-offs depending on the task and its requirements is necessary [Marriott et al. 2018].

To get a better understanding of these trade-offs, we provide a preliminary user study on five input modalities for a 2D shape tracing task. We investigate eye tracking, head tracking, hand motion tracking, and hand tracking through data gloves in respect to task completion time, accuracy, and user feedback. We compare these input methods to a touch baseline.

2 RELATED WORK

Previous work studies touch, eye tracking and gesture tracking in respect to accuracy, task completion time and subjective feedback as input modality for various tasks. We mention those that provide the foundations for our work, mainly focusing on drawing and selection tasks.

Regarding touch input, Hooten and Adams [Hooten and Adams 2011] conducted a study comparing errors and speed in drawing tasks for touch and mouse-based input. They came to the conclusion that touch-based interaction is up to twice as fast as mouse-based interaction. Regardless of the input method, curved shapes lead to a larger error than linear shapes.

As one of the first applications allowing to draw in 3D by hand movement, Crowley et al. [Crowley et al. 1995] developed the Finger Paint application in 1995, which allows drawing on the screen without touching it. Nowadays, with low-cost depth cameras available, there are even more possibilities for gesture recognition. Sutton [Sutton 2013] has developed the Painter Freestyle software, which allows drawing by hand movements in space, detected by the Leap Motion controller. Lyu et al. [Lyu et al. 2017] developed a drawing environment, in which hand gestures can be used to move a virtual airbrush across the screen as if it was fixed on the finger. Kim et al. [Kim et al. 2018] combine hand movements and touch in their 3D drawing environment, using gestures for rough sketching and touch input for the details.

Ware and Mikaelian [Ware and Mikaelian 1987] conducted two eye tracking studies looking at different eye tracking selection methods as well as target variables. Their results show that input with an eye tracker is faster than other conventional input methods, if the target size is big enough. The study by Sibert and Jacob [Sibert and Jacob 2000], in which the participants performed two different selection tasks, also led to the conclusion that eye tracking is significantly faster than selection with the mouse.

Previous work on the above mentioned input methods mainly compares them to mouse or keyboard entry. Our goal is to broaden this set of work adding further comparisons and different tasks.

3 USER STUDY SETUP

We conducted an exploratory user study to compare the input methods eye tracking, head tracking, hand motion tracking, and data gloves to touch input. Participants were told to trace various geometric shapes on the screen, as seen in Figure 1. Drawing speed, accuracy, and usability were measured to determine differences between the input methods. 20 people participated in the user study. Almost all of them were university students, most of them from the field of Computer Science. The participants' average age was 24.15 (SD = 6.84) years, 6 of them were female.

To enable drawing with various input methods on a computer screen, we implemented a drawing application with Unity. We conducted the eye tracking condition using a Tobii Eye Tracker 4C[1]. Hand motion was tracked using a Leap Motion controller[2]. The head movements were recorded by a VIVE tracker[3] mounted to a head strap. SenseGloves[4] were used as data gloves together with a VIVE tracker to record the spatial position of the gloves. An Apple iPad Air 2[5] was used for the touch input condition.

[1]https://www.tobii.com
[2]https://www.ultraleap.com
[3]https://www.vive.com
[4]https://www.senseglove.com
[5]https://www.apple.com

Methodology: The user study was conducted in a repeated measures design with five conditions, counterbalanced with Latin Square and in randomized order. Since the accuracy of tracing depends on whether a shape is linear or curved [Hooten and Adams 2011], we conducted the study with two curved, two linear and one combined shape. Every participant was assigned to one of five groups, and then used every input method once, tracing one of the five shapes with it. The geometric shapes fill a square with an edge length of max. 18cm. Since the distance that is maintained when using the iPad is smaller than the distance to the computer screen, a maximum size of 12cm was chosen. We assume that the participants would keep a distance of about 60cm to the screen and 40cm to the iPad based on measurements from a pilot study.

Procedure: The study was conducted in a university laboratory. First of all, the participants signed a form of consent and completed a demographic questionnaire.

At the start of each run, the participants briefly familiarized themselves with the device by tracing a sine wave. Then the actual test condition began, in which the participants traced the first geometric shape. Drawing speed and accuracy were recorded and a screenshot was taken. Afterwards, the participants answered two questionnaires: the NASA TLX and a questionnaire with questions about user experience, advantages and disadvantages, and possible areas of application for the input device. We repeated this procedure with all other input methods and shapes. After having completed all five test conditions, the participants were asked to rank all five input methods from best to worst.

4 STUDY RESULTS

In the final ranking, almost all participants rated touch input as the best input method regarding the overall impression. The majority indicated hand motion tracking as second best input. Eye tracking was voted to third place by most of the participants. The fourth place was occupied by data gloves and the fifth place by head tracking, according to most participants.

Table 1 provides a summary of the study results. The following sections describe the results of the measurements in more detail. Figure 2 shows results of significant pairwise-comparisons of drawing error, time, and workload.

4.1 Drawing Accuracy

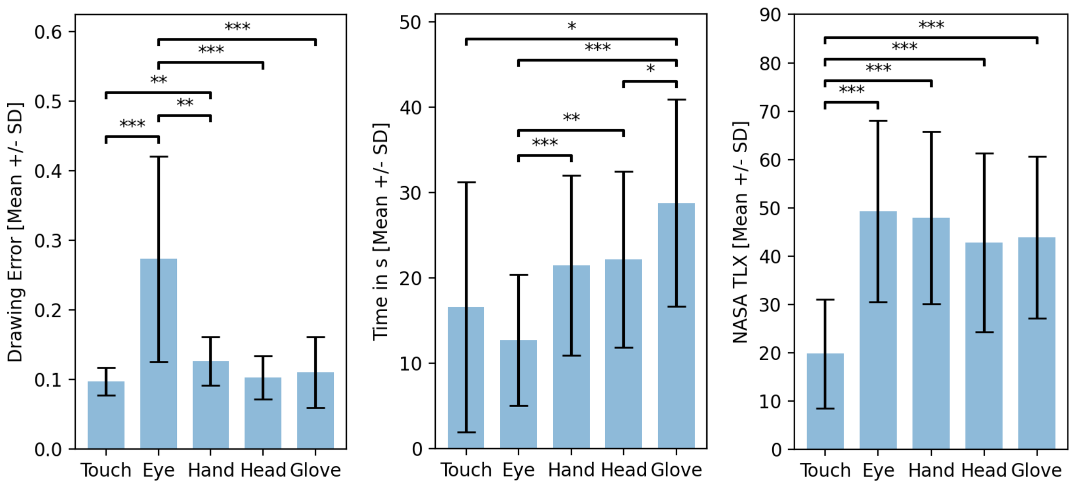
To compare the drawing accuracy of the different input methods, the distance between drawing position and nearest point of the geometric shape was measured. A repeated measures ANOVA was performed in order to analyze significant differences of the input methods regarding drawing accuracy. It showed a significant difference between conditions with $F_{4,85} = 19.20, p < .01$.

4.2 Drawing Time

In addition to the drawing error, the time in seconds needed by the participants to trace the shape was measured during the drawing process. The repeated measures ANOVA showed that there is a statistically significant difference between the input methods, with $F_{4,85} = 3.85, p < .01$.

Table 1: Overview of our study's results. Participants rated statements S1 to S3 from 1 to 5, 5 is best. The values in bold denote the best value for the respective measure.

Input	S1 M (SD)	S2 M (SD)	S3 M (SD)	NASA TLX M (SD)	Drawing error M (SD)	Time in s M (SD)
Touch	**4.900 (0.300)**	**4.700 (0.458)**	**4.500 (0.974)**	**19.833 (11.229)**	**0.098 (0.020)**	16.611 (14.658)
Hand motion tracking	2.950 (1.117)	2.600 (0.860)	3.350 (1.062)	48.000 (17.831)	0.127 (0.035)	21.522 (10.542)
Eye tracking	2.850 (1.314)	1.950 (0.973)	2.900 (1.513)	49.292 (18.713)	0.274 (0.148)	**12.752 (7.691)**
Head tracking	1.950 (1.117)	2.700 (1.100)	2.600 (0.800)	44.792 (16.838)	0.103 (0.031)	22.217 (10.315)
Data gloves	2.750 (1.043)	3.500 (1.025)	2.750 (1.090)	43.875 (16.757)	0.111 (0.051)	28.815 (12.123)



(a) Drawing error **(b) Time** **(c) NASA TLX**

Figure 2: Overview of the results regarding drawing error, time and workload. Significance of pairwise comparisons given as *** p<0.001, ** p < 0.01, * p < 0.05. The brackets denote the pairs.

4.3 Subjective Results

The participants answered a subjective questionnaire at the end of each condition. They should evaluate three statements based on a Likert scale ranging from strongly disagree (1) to strongly agree (5). The Friedman test showed a significant difference between conditions for the statement *"I would like to use this input method frequently."* (S1) with $X^2(4) = 37.09, p < .01$. Pairwise comparison Wilcoxon test showed that participants preferred touch input (M=4.90) over eye tracking (M=2.85, z=-3.62), hand motion tracking (M=2.95, z=-3.72), head tracking (M=1.95, z=-3.86) and data gloves (M=2.75, z=-3.92), p < .001. The test also showed that the participants would like to use the eye tracking (M=2.85, z=2.06) and the hand motion tracking (M=2.95, z=2.20) more regularly than head tracking (M=1.95), p < .05. No significant differences were found for the remaining tests.

For the statement *"I could accurately follow the shape with this input method."* (S2), the Friedman test showed a significant difference between the conditions with $X^2(4) = 43.27, p < .01$. The pairwise comparison Wilcoxon test showed that participants preferred touch input (M=4.70) over eye tracking (M=1.95, z=-3.92), hand motion tracking (M=2.60, z=-3.92), head tracking (M=2.70, z=-3.82), p < .001, and data gloves (M=3.50, z=-3.28), p < .01. Besides the test also showed that the participants rated the data gloves (M=3.50) as more accurate than eye tracking (M=1.95, z=3.06), p < .01, hand motion tracking (M=2.60, z=2.43) and head tracking (M=2.70, z=2.10), p < .05. The test also showed that hand motion tracking (M=2.60) was rated more accurate than eye tracking (M=1.95, z=2.02), p < .05. No significant differences were found for the remaining tests.

A Friedman test showed a significant difference between conditions for the statement *"I liked using this input method"* (S3) with $X^2(4) = 27.80, p < .01$. Pairwise comparison Wilcoxon test showed that the participants liked touch input (M=4.50) best compared to eye tracking (M=2.90, z=-2.92), hand motion tracking (M=3.35, z=-3.12), p < .01, head tracking (M=2.60, z=-3.30), and data gloves (M=2.75, z=-3.40), p < .001. No significant difference was found for the other tests.

4.4 Subjective Workload

The subjective workload was measured using the NASA TLX [Hart and Staveland 1988]. For each input method, the total workload and partial workloads were recorded in order to be able to address the individual areas. The Friedman test showed a significant difference between the conditions for overall load with $X^2(4) = 41.04, p < .01$.

The Friedman test showed a significant difference between the conditions for mental demand with $X^2(4) = 29.45, p < .01$.

Regarding physical demand the Friedman test showed a significant difference between the conditions with $X^2(4) = 41.38, p < .01$.

For temporal demand, no significance was found using the Friedman test, with $X^2(4) = 5.81, p = .21379$.

The Friedman test showed a significant difference for perceived performance with $X^2(4) = 20.06, p < .01$. Effort was rated significantly different for the conditions with $X^2(4) = 36.47, p < .01$. The Friedman test also showed a significant difference between conditions for frustration with $X^2(4) = 43.69, p < .01$.

4.5 Correlation

The Spearman correlation test showed that the drawing error correlates significantly with the required time when using touch as input method, $r = -.480, p = .034$. Besides the test showed that drawing error also correlates significantly with the required time when using eye tracking as input method, $r = -.448, p = 0.049$. No significant correlations were found for the remaining tests.

5 DISCUSSION AND LIMITATIONS

When rating the input modalities, participants mentioned accuracy and the ease of use in their comments, which seemed influencing factors for the decisions. The touch baseline scored best in all categories. When touching the screen, the finger is more stabilized, which results in drawings with less jitter (Figure 1). This factor is also reflected in the accuracy results. The accuracy is also mentioned as a positive characteristic by 4 participants. However, it should be noted that all participants were already used to touch input.

In contrast to touch input, limbs were not stabilized during input with hand motion tracking and data gloves, leading to decreased accuracy. As the hand moved freely in space, it was strenuous for the participants to trace the shape, as 11 participants mentioned. The hardware of the data gloves was more precise than of the hand motion tracking, which had to be restarted in some cases. This could have led to a higher drawing error of hand motion tracking and was criticized by 12 participants.

Eye tracking took third place in the overall evaluation. People's eye movements are not linear but consist of sudden, rapid saccades [Jacob 1991]. Therefore, it was difficult for the participants to concentrate their gaze on the shapes and to move their eyes along the line. Many participants noted that it was strenuous to keep their eyes still during the drawing process. This also affects the drawing error and workload, which were highest for eye tracking. One advantage of drawing with eye tracking was that the shapes could be traced very quickly with the eyes, because the eyes move much faster than limbs. It is probably not a suitable input for precise drawing tasks, but it can be used to sketch rough shapes. To improve the accuracy of eye tracking one could provide additional stimuli that help the participants to follow the shapes in a future prototype. [Demšar and Çöltekin 2017; Lorenceau 2012; Majaranta and Bulling 2014]. Additionally, eye tracking received positive feedback from the participants such as *"fun to use"* (4 participants), *"easy to use"* (4 participants) and *"hands are free"* (4 participants). We believe especially the aspect of hands-free interaction is worth looking into further, as it holds potential for accessible interaction for people that are not able to use their hands [Hornof and Cavender 2005]. Head tracking also benefits from hands-free interaction, but was voted last in the ranking, although together with touch input it had the highest accuracy. As a reason for that 5 participants stated that they felt *"uncomfortable"* with the input, as they had to perform unusual movements that they would not want to do in public. Furthermore, 3 participants found head movement exhausting.

Our study is a preliminary study, which focuses on a 2D shape tracing task and approaches the different input devices exploratively. The suitability of input methods often depends on the tasks [Marriott et al. 2018], which results in a limited generalizability of the results. Thus, for other tasks, further explorations are necessary. For a 3D tracing task, touch would perhaps not surpass the other input methods. Considering 3D shapes might be a next step. However, 2D shapes are relevant in AR where you might have 3D space, but often still rely on 2D output. Here, our study provides interesting starting points for further investigations.

6 CONCLUSION AND FUTURE WORK

We empirically compared five different input methods for a 2D shape tracing task: Touch, eye tracking, hand motion tracking, head tracking, and data gloves. Our results showed that touch input scored best in terms of usability, workload, and drawing error. In the overall evaluation, touch input was also rated best. However, it should be noted that the other technologies are far less mature, sophisticated, and popular than touch input. Assuming that the new technologies become further developed and provide a higher accuracy, they might have potential. Many participants were enthusiastic about the new input methods, but stated that they need to be improved to ensure reliable input.

Eye tracking especially proved to be a fast input method. It is also available directly within some head-mounted displays, which opens up new possibilities for eye-tracking-based interactions in Immersive Analytics and Situated Visualization. Another interesting aspect is the possibility of hands-free interaction combined with VR/AR technologies, which could be especially useful for visualizations "in the wild", such as assisting construction workers or medical doctors with in-situ data representations. Hands-free interaction, as provided by eye or head tracking, could also provide a more accessible way of performing visual data analysis for those who are not able to use their hands because of a disability. We hope our contributions are an interesting starting point to explore these directions further.

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