Precueing Compound Tasks in Virtual and Augmented Reality

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Abstract

This paper addresses the challenge of determining the quantity and composition of visual task cues for effective precueing in virtual reality (VR) and augmented reality (AR) applications. AR and VR can seamlessly overlay additional visual information to help people improve work efficiently and reduce errors while working through the steps of procedures, but the effectiveness of such task assistance depends on the presentation format and amount of information given. Prior research has found benefits of supplemental visual cues for giving future hints for upcoming steps in procedural tasks, though many experiments have predominantly focused on simplified tasks, which leaves a gap in our understanding of the potential for mixed reality to guide users for compound tasks and instructions. We present an experiment assessing different visual cues in VR to test a user's ability to harness distinct precueing information streams separating cues for object search and object placement for multi-step procedures. The results demonstrate that when users complete compound tasks involving multiple types of subtasks and instructions that combine different types of information, users are not able to take advantage of information about future steps for effective precueing. However, the addition of even simple interaction cues significantly improved task performance for both time and errors.

Keywords: virtual reality, augmented reality, task guidance, interaction precueing

1 Introduction

The freedom of providing extra information to the user's view in virtual reality (VR) and augmented reality (AR) has a strong potential to benefit performance for completing procedural tasks. One common application of such technology is task guidance, as users could benefit from having instructions and tips available while working through the steps of a procedure. For example, VR training applications can provide tips and instructions to help a user learn new operations, such as for vehicle operation [3] or safety procedures [4]. Mixed reality applications offer real-time guidance, aiding users in performing tasks efficiently without requiring prior knowledge of the procedure by providing step-specific information. Applications can also provide hints about upcoming steps to help the user plan ahead for even greater efficiency [2]. This is referred to as *precueing* [1], a technique of presenting cues or future information about future steps in a sequence.

Mixed reality technology offers various information presentation options for task guidance. However, a key design challenge is determining the optimal amount and type of information for effective precueing. Too much information may overwhelm or distract users, especially when presenting information for multiple future steps. Conversely, insufficient information may hinder users' efficiency in working through a sequence of steps quickly.

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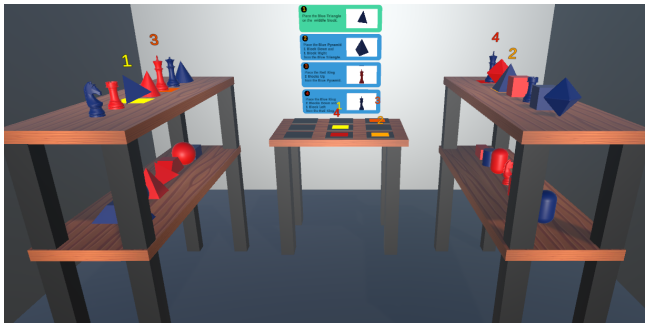

Figure 1: The virtual environment used for the study. The image shows the layout, where participants were positioned between the two shelves with the placement grid straight ahead

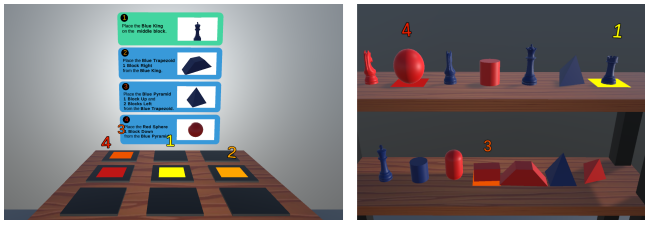

Figure 2: The left image shows how the instructions were shown above the 3x3 placement grid. The number of instructions shown and the inclusion of placement cues (floating numbers and bright squares) depended on the experimental condition. The right image displays shelves with target objects and search cues.

Our research addresses the challenge of precueing future steps for procedures combining multiple types of subtasks (i.e., 3D search, object placement) while interpreting different information from instructions (e.g., text, image, spatial relations). While research on precueing has studied the effectiveness of visual cues to improve task performance, prior work (has mainly focused on procedures with simplified tasks involving a single interaction type. Our research advances this work by studying more complex procedures and compound instructions.

This paper presents a new experiment on precueing for compound tasks requiring search and object manipulation while following instructions combining text and images. We present a VR experiment to simulate additional information added to a base assembly context to maintain control over different types of visual cues The study assesses the ability of users to use different types of precueing information by separating cues for object search and object placement, and we investigate how many steps ahead users can effectively process the precues for procedural tasks. The study provides new knowledge of design implications for the use of interaction cues to precue future steps for compound procedural tasks.

2 Experiment

We conducted a controlled experiment to evaluate whether participants could effectively use precueing hints for future steps to improve task completion on a compound procedural task involving 3D search and object placement. Our experiment tests (a) whether users can effectively take advantage of information for future steps,

and (b) whether visual cues for certain types of subtasks are more important than others.

- **H1:** *Visually presenting additional future steps in compound tasks will reduce task completion time.*
- **H2:** *The inclusion of in-world visual cues will improve task performance (i.e., reduce errors and reduce completion time) on compound procedures.*
- **H3:** *The presence of in-world visual cues will reduce the need to refer back to full instructions.*

To address the hypotheses, the experiment controlled three independent variables following a 2x2x4 mixed design. Two types of visual cues were independently controlled between-subjects, while the number of precued steps varied within-subjects. Below are descriptions of each variable and each level of the variables:

- **Search Cues:** Whether or not the search cues were present.
- **Placement Cues:** Whether or not the placement cues were present.
- **Number of Steps:** How many steps are shown at a time in the instructions list (Figure 2). This is also controlled and this was either one step, two steps, three steps, or four steps.

In the experiment, participants engaged in a task comprising subtasks, each involving finding, picking up, and placing a designated object in a virtual environment. The task necessitated physical turning, limited walking, and reaching within the virtual workspace. The virtual setting, depicted in Figure 2, had participants positioned in front of a central table where instructions were displayed, with two shelves flanking their primary location containing virtual objects. Trial included 26 unique objects randomly distributed across shelves.

In this study, we ensured visually distinct objects, selecting from geometric solids (cube, cylinder, capsule, rectangle, pyramid, trapezoid, cone, octahedron, tetrahedron) and chess pieces (king, queen, knight, rook), each in red and dark blue (26 unique objects). Each trial consisted of 20 tasks, with specific objects randomly assigned to each step. Visual instructions, displayed above the central table, guided participants to place objects on a 3x3 grid. Instructions included text indicating the object and its placement relative to the previous task's destination. The initial task involved centering the object on the grid, and each instruction was accompanied by an image of the corresponding object

Participants had to complete each task successfully before receiving updated instructions. To maintain search difficulty, selected objects were replaced with virtual duplicates on shelves, and the previously placed object disappeared after the next successful placement. This ensured only one reference object was on the grid per task, sustaining a consistent level of difficulty and visual complexity.

The study was conducted in person, starting with informed consent and a background questionnaire. The experimenter explained the study task and guided participants through a tutorial trail with a three-task example procedure. After practicing and demonstrating proficiency, participants completed four procedure trials (one for each *number of steps*), each with 20 tasks.

3 Results and Conclusion

The study, approved by our institution's ethics review board, included 48 participants (34 male, 14 female). Participants ages ranged from 18 to 30, with a median age of 22.

We tested the effect of in-world cues both search and destination cues and the number of steps on user performance. Task time was analyzed based on the average time per step for the core steps of the procedure. We conducted a three-way mixed ANOVA for the two

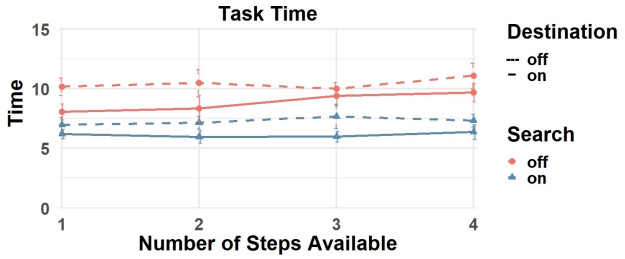

Figure 3: **Time results** as average step completion in seconds show search cues and destination cues each independently had significant effects for faster task time. Error bars show standard error.

between-subjects factors (both cues) and one within-subjects factor (number of steps shown) after doing outlier removal and checking test assumptions. The results indicate that the number of instruction steps shown did not significantly influence task time. So the difference between the means for task time for 1 step, 2 steps, 3 steps, and 4 steps was not significant ($F(2.44, 107.52) = 1.49, p=0.227$). Therefore, we do not find evidence to support hypothesis **H1**. Conversely, our analysis demonstrates that both destination and search cues exert a notable influence on time, supporting hypothesis **H2**. So the difference between the means for task time for search cue on and off situation was significant ($F(1, 44) = 33.28, p<0.001$) and similar for destination cue($F(1, 44) = 6.68, p<.05$). We conducted the same type of ANOVA test for task error, finding if the search cues are on, participants significantly tend to make fewer errors ($F(1, 44) = 4.11$, $p < 0.05$). Similarly, there is a two-way interaction effect between search and destination cues. Participants tends to make fewer errors when both cues are on than both cues are off($F(1,44) = 5.13$, $p < 0.05$). The study also tested how the visual cues affect users' viewing and head movement behaviors by analyzing how often participants referred to the full instructions. This analysis revealed a statistically significant reduction in participants' visual engagement when either one or both of the cues were activated, supporting **H3**. This means the number of looks at the panel reduces if search cues are on ($F(1,44) = 13.62, p<.001$) or destination cues are on ($F(1,44) = 33.70, p<.001$) or both cues are on.

The study found that providing cues for both search and destination positively affected task completion time and error rate. Surprisingly, displaying future steps did not enhance task performance for the compound task and, in fact, might increase the likelihood of errors. Overall, these findings contribute to improving our understanding of designing effective task guidance interfaces in AR and VR applications.

Acknowledgments

This work was supported in part by the DARPA Perceptually-enabled Task Guidance (PTG) Program under HR00112220005.

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