# Boundaries facilitate spatial orientation in virtual environments

Jonathan W. Kelly
Iowa State University, USA
jonkelly@iastate.edu

Jason Terrill
Iowa State University, USA
terrill@iastate.edu

Moriah Zimmerman
Iowa State University, USA
moriahz@iastate.edu

Taylor A. Doty
Iowa State University, USA
tdoty@iastate.edu

Lucia A. Cherep
University of Arizona, USA
lacherep@arizona.edu

Melynda T. Hoover
Iowa State University, USA
mthoover@iastate.edu

Nicole R. Powell
Iowa State University, USA
nrpowell@iastate.edu

Owen J. Perrin
Iowa State University, USA
operrin@iastate.edu

Stephen B. Gilbert
Iowa State University, USA
gilbert@iastate.edu

## ABSTRACT

Teleporting is a popular interface for locomotion through virtual environments (VEs). However, teleporting can cause disorientation. Spatial boundaries, such as room walls, are effective cues for reducing disorientation. This experiment explored the characteristics that make a boundary effective. All boundaries tested reduced disorientation, and boundaries representing navigational barriers (e.g., a fence) were no more effective than those defined only by texture changes (e.g., flooring transition). The findings indicate that boundaries need not be navigational barriers to reduce disorientation, giving VE designers greater flexibility in the spatial cues to include.

## CCS CONCEPTS

**• Applied computing → Psychology**; **• Human-centered computing → Virtual reality**.

## KEYWORDS

Virtual reality, Spatial navigation, Triangle completion, Teleporting

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## 1 INTRODUCTION

The most natural way to explore a virtual environment (VE) is to walk. However, the size of the physical environment occupied by the user is finite, whereas the size of the VE can be infinite. One of the most popular locomotion interfaces to overcome this challenge is teleporting (Figure 1), in which the user is instantly transported without any self-motion cues. In one form of teleporting (**partially concordant** teleporting [2]), the user rotates their viewpoint by rotating their body but teleports to translate (i.e., change position). In another form (**discordant** teleporting [2]), the user teleports to translate and rotate. Teleportation is disorienting [1], but disorientation can be mitigated in VEs containing boundaries such as room walls or a fence (landmarks alone are ineffective [2]).

Research in spatial cognition indicates that boundaries hold privileged status over other navigational cues like landmarks [2, 3]. But what defines a useful boundary? Should a boundary impede navigation for it to be a useful orienting cue? Neuroscience research [4] finds that walls are processed in a different brain region from other visual discontinuities that do not impede navigation, such as a texture discontinuity on the ground (e.g., a change in flooring). Yet, behavioral research [6] indicates that visual barriers are useful cues to spatial memory, whether or not they impede movement.

To evaluate the usefulness of boundary cues during VR navigation, participants performed triangle completion (travel two outbound legs before pointing to the path origin) using two teleporting interfaces varying in available self-motion cues. They performed this task in five VEs presenting different visual boundaries to determine the types of boundaries that support spatial orientation.

## 2 METHOD

### 2.1 Participants

Thirty-eight students (18 men, 20 women; average age = 20.3 years) at Iowa State University participated in exchange for a gift card.

### 2.2 Design and materials

Participants used two teleporting interfaces (partially concordant and discordant) to perform a triangle completion task in five VEs, experienced by wearing an HTC Vive head-mounted display (HMD).

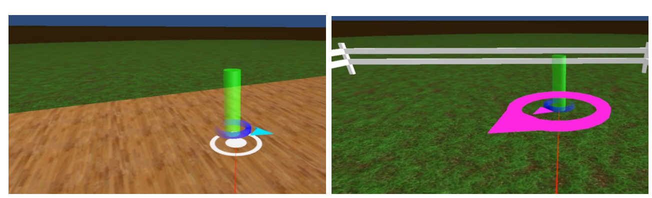

**Figure 1: Images of the texture VE with partially concordant interface (L) and fence VE with discordant interface (R).**


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The open field VE consisted only of a grassy ground plane. The fence VE added a low square fence, 9 by 9 meters (.75 meters tall), to the open field. The texture VE added a flat square on top of the open field. The square was 9 by 9 meters and was textured with a wood pattern. The drop-off VE was identical to the texture VE except that the square was elevated 2.5 meters above the grass. The classroom VE was modeled after a 9 by 9 meter university classroom. Objects such as desks and chairs were moved to the edge of the classroom.

Participants completed 8 trials for each combination of the primary independent variables (interface and VE), for a total of 80 trials. Interface was blocked and counterbalanced. Within each interface block, VE order was blocked and counterbalanced.

## 2.3 Procedure

After providing informed consent, the participant was introduced to the triangle completion task and the VR equipment. The participant then entered a training VE where they completed at least two practice trials with the first teleporting interface. The participant then completed the triangle completion task in each of the five VEs using the same interface. Next, the participant was instructed on how to use the second interface and again had an opportunity to practice before performing the task in the five VEs.

At the start of each triangle completion trial, a green post appeared marking the path origin. The participant traveled to the green post, which disappeared upon arrival. A yellow post then appeared, marking the first path leg. The yellow post disappeared upon arrival, followed by a red post marking the second path leg. Upon arrival at the red post, the participant attempted to point to the path origin by placing a blue circle at the remembered location.

# 3 RESULTS AND DISCUSSION

Performance was quantified as the absolute distance between the response location and the location of the path origin. Absolute distance error is shown in Figure 2.

Consistent with past research [2, 5], errors when using the discordant interface were larger than those with the partially concordant interface, and this was true for every VE ($p$ values less than .037).

When using the discordant teleporting interface, performance in the open field was worse than in all other VEs ($p$ values less than .001), whereas performance in the classroom was better than in all other VEs ($p$ values less than .001). The other three VEs led to intermediate errors, although performance in the drop-off VE was significantly worse than in the fence VE ($p$ = .02) and texture VE ($p$ = .05), which did not differ from one another ($p$ = .56).

When using the partially concordant teleporting interface, performance in the open field was worse than in all other VEs ($p$ values less than or equal to .001), whereas performance in the classroom was better than in all other VEs ($p$ values less than .027). The other three VEs led to intermediate errors that did not differ significantly from one another ($p$ values greater than .53).

# 4 CONCLUSIONS

Triangle completion performance was worse when using the discordant teleporting interface compared to the partially concordant interface, reflecting the importance of rotational self-motion cues. A key question was whether and which environmental cues would

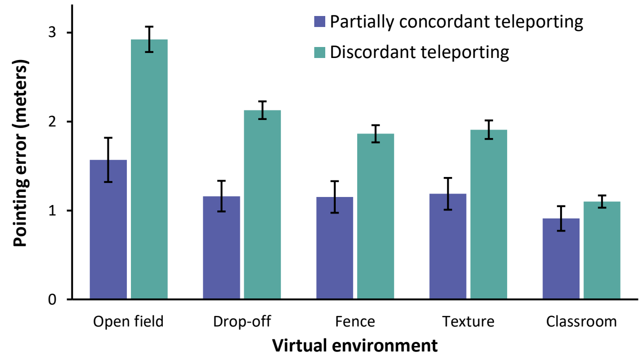


**Figure 2: Absolute error when pointing to the path origin.**

mitigate disorientation. Boundaries were clearly helpful: the open field VE led to worse performance compared to all other VEs. The drop-off and fence VEs, which contained navigational barriers, were no better than the texture VE, which contained a texture discontinuity (a flooring change) that did not impose a navigational barrier. This indicates that any boundary can useful for staying oriented, regardless of whether it represents a navigational barrier.

The classroom led to the best performance, likely because it contained many spatial cues (boundaries defined by walls, plus lots of landmarks). The vast number of cues enabled greater reliance on piloting—navigation by landmarks—and reduced the advantage of the partially concordant teleporting interface.

Results from this study grant additional flexibility to designers of virtual environments. Boundaries should be included in VEs when feasible, but they need not be navigational barriers. Furthermore, combining ample landmarks with boundaries will create spaces that are easy to navigate and mitigate spatial disorientation.

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