# Individual differences in teleporting through virtual environments: A latent profile analysis

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## ABSTRACT

Teleportation in virtual reality (VR) affords the ability to explore beyond the physical space. Previous work has demonstrated that this interface comes at a spatial cognitive cost – though, upon closer inspection, not everyone appears similarly affected. A latent profile analysis identified three groups that significantly differed on spatial updating performance and follow-up analyses showed significant differences in objective measures of spatial ability (e.g., mental rotation and perspective-taking). These results suggest that there are individual differences in domains of spatial cognition that are related to how well a user may keep track of his or her location while teleporting in VR.

**Keywords:** Navigation, Spatial cognition, Virtual reality, Teleporting

**Index Terms:** K.6.1 [Human-Centered Computing]: Human Computer Interaction—Interaction ParadigmsVirtual Reality;

## 1 INTRODUCTION

The teleportation interface is widespread in virtual reality (VR), most likely due to ease of use and reduced effects of cybersickness [6]. However, the popularity of teleportation interfaces appears to come at a spatial cognitive cost. In particular, the lack of self-motion cues when teleporting disrupts spatial updating, the process of keeping track of self-location during travel [4, 7]. Disorientation represents a failure of spatial updating, and can only be corrected by using piloting cues (e.g., landmarks) to reorient. Yet, are all individuals disoriented similarly by the removal of self-motion cues? For example, does performance in other domains of spatial cognition (e.g., mental rotation) relate to the likelihood that disorientation will occur? Objective and subjective (i.e., self-report) measures of spatial ability may offer some insight into the variability associated with spatial updating performance. Therefore, the current study examined the relationship between individual differences in spatial ability measures and spatial updating performance in virtual environments (VEs) that vary in self-motion cues and visual piloting cues.

### 1.1 Locomotion interfaces

A compelling feature of VR is the ability to walk and rotate physically. However, due to the limited physical space, locomotion interfaces, such as teleportation, are necessary to explore large VEs. A typical implementation of teleportation is to physically rotate the body, but teleport to translate. This method of teleportation is therefore **partially concordant** with the user's body. Another form of teleportation has the user position a marker on the ground to specify a new location and orientation and teleportation occurs instantly. This teleportation method is considered **discordant** from the body, as rotational and translational self-movement cues are restricted during navigation

Figure 1: Virtual environments displayed in the HTC Vive.

### 1.2 Current experiment and hypotheses

The current study evaluated spatial updating performance in VR and examined the relationship between VR performance and objective and subjective measures of spatial ability. The VEs included an open field and a classroom that included walls and furniture (see Figure 1). Three locomotion interfaces were included: walking, partially concordant teleporting, and discordant teleporting. Participants performed a triangle completion task by navigating two outbound path legs before pointing to the unmarked path origin. It was predicted that absolute errors (calculated as the absolute distance between the origin of the path and the participant's response) would be lower for partially concordant teleporting compared to discordant teleporting and that walking would have the best performance. Errors were also predicted to be lower in the classroom VE compared to the open field. These hypotheses were consistent with research on the relative contributions of rotational self-motion cues on simple spatial tasks [4] and with past work on locomotion interfaces [1].

A latent profile analysis (LPA) was employed to categorize participants based on VR performance. Subsequently, classes (categories) were compared on non-VR measures of spatial ability and demographics. LPA is a person-centered approach that can identify groups within a heterogeneous sample. This analysis is a probabilistic, model-based method that estimates posterior probabilities of class membership and groups individuals into latent classes based on the probability of being in each class, with individuals grouped based on the highest probability of class membership. Model selection requires consideration of theory, model class sizes, parsimony, as well as statistical support. Following the classification of group membership, one-way ANOVAs were used to determine how classes differed on measures of spatial ability. Since this was an exploratory analysis, there were no specific predictions regarding the number of classes.

## 2 METHOD

One-hundred and twenty-four students (67 men, 57 women) at Iowa State University participated in exchange for course credit. Data from eight participants were removed leaving 116 participants (62 men, 54 women) for the repeated measures ANOVA of VR performance. For the LPA, multivariate outliers were examined and one participant was removed. The total sample size for the LPA was 115 (62 men, 53 women).

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## 2.1 Spatial ability measures

Participants completed the Vandenberg Mental Rotation Test [8], the Santa Barbara Sense of Direction scale [3], the Perspective Taking/Spatial Orientation Test [5], and the Philadelphia Spatial Abilities Scale (PSAS) [2]. Participants were also asked to estimate how many hours of video gameplay they engaged in per school day and weekend day in the last calendar year. Participants also reported any previous experience with VR.

## 2.2 Materials

The HTC Vive HMD displayed the VEs, and graphics were generated on a Windows 10 computer with an Intel 6700K processor and Nvidia GeForce GTX 1070 graphics card. Unity software displayed stereoscopic images at 1080 × 1200 resolution per eye with 100° horizontal × 110° vertical binocular field of view. Images refreshed at a rate of 90 Hz and reflected the head position and orientation tracked by the Lighthouse tracking system sold with the Vive. One wireless handheld controller, sold with the Vive, was used to control teleporting interfaces and responses.

## 2.3 Procedure

After signing the informed consent, the participant was given verbal instructions on the triangle completion task. The participant donned the HMD and was trained on the triangle completion task with each of the three locomotion interfaces. During testing, interfaces were pseudo-randomized, and VE was blocked. Once all six conditions were complete, the participant sat in front of a lab computer and completed the spatial ability measures. After the measures were completed, the participant was debriefed and given course credit.

# 3 RESULTS

As predicted, absolute error was significantly lower for walking compared to partially concordant teleporting ($p$<.01), and partially concordant teleporting was significantly lower than discordant teleporting ($p$<.01). Additionally, errors were significantly lower in the classroom VE compared to the open field VE for partially concordant ($p$<.01) and discordant teleporting ($p$<.01). Bivariate correlations revealed that men had significantly lower absolute errors across both teleportation interfaces in each VE and demonstrated higher spatial ability across mental rotation, perspective-taking, and the PSAS. Men also reported higher average weekly video gameplay.

Although there was no specific prediction for the number of classes, fit indices for the LPA revealed a three-class model (see Figure 2). This model is in line with previous research that identified three clusters of individuals who were asked to integrate between routes in a virtual town [9]. The three classes the LPA identified included: a class that performed well across all VR conditions ("accurate integrators "; 51% n = 59), a class that utilized the visual piloting cues in the classroom VE to stay oriented ("imprecise integrators" 37%, n = 42), and a class that performed poorly across both VEs ("imprecise non-integrators"; 12%, n = 14). Accurate integrators had significantly lower absolute errors compared to imprecise integrators and imprecise non-integrators across all conditions ($p$'s<.01), except for the classroom walking condition. The imprecise integrators and imprecise non-integrators performed similarly, except imprecise integrators had significantly lower errors for partially concordant teleporting ($p$<.01) and discordant teleporting ($p$<.01) in the classroom VE.

Accurate integrators had significantly better scores on mental rotation ($p$'s<.01) and perspective-taking ($p$'s<.01) compared to imprecise integrators and imprecise non-integrators respectively. Imprecise integrators and imprecise non-integrators did not significantly differ on mental rotation or perspective-taking. None of the groups significantly differed on the self-report measures of spatial ability. These results are consistent with the notion that performance on spatial measures would be related to spatial updating performance in VR; however, it suggests that self-report measures of spatial ability are not related to performance in VR.

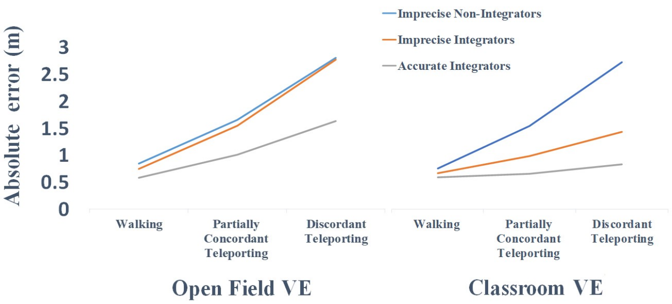

Figure 2: Absolute errors (in meters) for the three-class model of VR performance.

# 4 CONCLUSION

Performance in VR was consistent with previous literature regarding increased disorientation associated with the removal of self-motion cues. The LPA demonstrated that individuals do differ in VR performance and when grouped together, VR performance is differentially related to measures of objective spatial ability. Future work should focus on identifying individuals whose VR performance is not enhanced via available visual cues and offer modifications for the locomotion interfaces.

# ACKNOWLEDGMENTS

This work was pre-registered on the Open Science Framework (https://osf.io/xc8v5/) and was based upon work supported by the National Science Foundation under Grant Number CHS-1816029.

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