

# Remote Mobile Augmented Reality for Spatial Cognition

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## ABSTRACT

Augmented Reality (AR) experiments are typically implemented in controlled conditions that are guided by experimenters. The paucity of research on remote AR experiments leads to difficulties for many researchers when conducting remote user studies. Our work provides a preliminary investigation of spatial perception in AR via mobile devices. The initial findings suggest the use of mobile AR with smartphones for assessing and training perception is feasible and that data collection with smartphones is reliable.

## CCS CONCEPTS

• **Human-centered computing** → **Augmented reality**; **Empirical studies in HCI**; • **Applied computing** → *Psychology*.

## KEYWORDS

usability, mobile augmented reality, spatial cognition

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## 1 INTRODUCTION

Augmented reality technology is now widely available at the consumer level in modern smartphones. As AR applications for entertainment, education, healthcare, training, and communication become more widespread and general, the importance of user interactions increases. One concern with the current technology is that virtual objects may not be perceived in the same way as real world objects. This difference, called a loss of *perceptual fidelity*, can lead to applications not working as well as intended. The current work evaluated the perceptual fidelity of augmented reality in smartphones in realistic, everyday contexts (i.e., in the wild).

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This gives our experiments more inherent variance, but through careful study design we can learn about perceptual fidelity of these devices in the situations in which they are most likely to be used. In this paper, we first briefly introduce two AR experiments in remote settings. We then report the challenges we encountered in our experiments, specifically dealing with participant recruitment, experiment procedure, and data collection. We discuss our solutions to these problems, and give suggestions on remote experimental design and implementation for mobile AR.

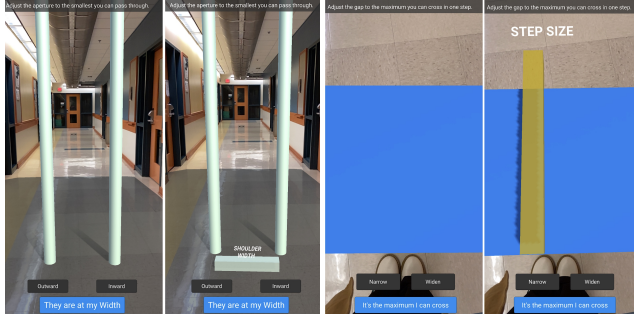
## 2 EXPERIMENTS

Our research focus is on spatial perception with AR via the most easily accessed mobile devices. Specifically, we developed two remote applications for both iOS and Android platforms and distributed them through the respective app stores. Experimental data was returned to us via email automatically whenever a participant completed an entire experiment.

In the first experiment, we investigated two judgments of action capabilities (also called *affordances*) with virtual objects presented through smartphones: passing through an aperture and stepping over a gap (Figure 1). The goal was to assess whether viewers could make judgments of their abilities to act on AR objects as well as to evaluate the utility of a cue that provided more information about their body size to aid their judgments. In this experiment, virtual poles in front of participants or a virtual gap on the ground appeared; participants were asked to make a judgment as to whether they could pass through the poles and step over the gap. Participants were required to find an open space and to scan the ground with their phones to detect the ground plane, thus generating the virtual stimuli in front of them. For both affordance judgments, the virtual objects needed to be attached to the ground plane, so accuracy of ground detection is critical for the app. Results showed conservative judgments for both actions, but increased accuracy after training with AR cues.

The second experiment, a distance estimation study, evaluated whether social cues affect egocentric distance judgments of a standing or coughing, masked or non-masked virtual human avatar (Figure 2). In this experiment, people were asked to make a verbal estimate of how far away a virtual avatar (in the conditions described previously) was from them; the avatar was displayed

through their smartphone. Like experiment 1, the ground plane detection mechanism was important for this study as well. We found that distance estimates were accurate with no effects of mask or coughing.



(a) Passing Through Experiment (b) Stepping Over Experiment

**Figure 1: Screenshot of passing through apertures (without the AR cue on left and with the AR cue on the right) and stepping over gap scenario.**

### 3 CHALLENGES

#### 3.1 Participant recruitment

Smartphone-based AR requires participants to own a mobile device that has AR capability, i.e., an iPhone running iOS 11 or later, or an Android phone running Android 7.0 (Nougat) or later. The high prevalence of smartphones makes recruiting participants to run our remote applications feasible in terms of hardware accessibility. We recruited 26 participants for each experiment with mean age of 32.61 years (19-69). The distributed experiment setup allowed us to involve participants from different continents (i.e., North America, Europe and Asia), with a large age range. The data of five people were faulty due to an avatar placement error and were discarded. Thus, we had 21 participants for Experiment 2.



**Figure 2: A view of Non-Masked Non-Coughing, Non-Masked Coughing, Masked Non-Coughing and Masked Coughing Avatars in distance estimation experiment.**

#### 3.2 Experimental Process

**3.2.1 Body Measurement.** The measurement of certain body dimensions of a participant was necessary for Experiment 1, as affordance judgments investigate observers' perceptions of their action capabilities given the constraints of the environment relative to their body capabilities. Normally, measurements would be taken by experimenters several times in the lab to reduce measurement error. In the remote experiment, we asked participants to measure their shoulder width and maximum stride using their own tape measure as precisely as possible. Participants were shown a photograph illustrating the procedure they were to follow (Figure 3). For participants who could not find a tape measure, the system set a default value for their shoulder width to 0.5m (observed by [Pointon et al. 2018]), for the maximum stride to 0.88m (observed in [Creem-Regehr et al. 2019]). In cases where participants could not provide a reliable measurement, we also required them to report their height as an alternative body size index. The approach utilized to determine the reliability of the measurement is described in Section 3.4. Overall, even with precise instructions, the requirement to measure one's own body size or capability is a limitation of remote experiments.

**3.2.2 Environment Requirement.** An open space (indoor or outdoor) that extended up to 5 meters was required in our two experiments. In a remote study like this, it was hard to know where the participants actually stood. So, we forced the app to detect only the horizontal surfaces in the environment. The app then automatically chose the surface among all those detected that had the lowest height, given this would generally be the floor.

Based on our anecdotal experience in pilot testing the app for Experiment 2, we found that shadows were helpful for estimating the distance to the avatar. Also, direction of the shadows could change based on the ambient and positional lighting available in an indoor environment, which could help the participants to estimate distance to the avatar. So, we implemented shadows in this app given we did not know whether the participants would run the experiment in an indoor or outdoor environment.

**3.2.3 Protocol Design.** Unsupervised experiments result in the loss of interaction between participants and experimenters. Consequently, it is difficult to provide real-time support if participants encounter difficulty when running the AR applications. Therefore, clearer instructions on experimental procedure and more user-friendly interaction design should be given under these circumstances. We visualized how to utilize various AR functionalities in our applications and how to measure the specified body parts as images for illustrating our intention effectively. A refined graphical user interface (GUI) with good layout and no closely arranged text is more critical for a remote versus laboratory setting. Further, if participants encountered questions or problems, we told them to contact us for remote support.

In addition, one of the rules of our remote protocol design was to keep the number of trials to as few as possible. We were concerned that people would lose interest or become fatigued if there were too many repeated trials, which would likely influence the results of the experiments. Future work could consider using attention check

questions which would also be helpful to improve the quality of the data collected [Aust et al. 2013].

### 3.3 Data Collection

To retrieve experimental data from participants, the data was sent to us as an email attachment by the apps automatically. However, this way of sending the data back will only work if there is no sensitive information about the participants, and the acquired data is not more than 25 MB. To ensure the robustness of our data retrieval, we used a Google form to save data when there was an exception to the email process.

A reliable internet connection was a precondition that was checked at the beginning of the experiment. We implemented a 5 second timer during when the app would continuously search for a stable internet connection before sending the data back to the experimenter. If the timer ended before internet could be secured, participants were instructed to check the internet and restart the app. Upon restarting, if the app got a reliable internet connection, it would send the data immediately, and thus participants did not have to rerun the experiment due to loss of internet.

We also wanted to make sure that a single device could send unique data to us only once in the case of Experiment 2. So, after sending the data to us, the app responsible for Experiment 2 wrote a text file and stored it on the device to serve as proof that the data had been sent. If the app ran again, it would find the text file in memory and did not allow for further data collection.

### 3.4 Data Processing

Remote AR experiments, by their nature, introduce more variability compared to controlled lab settings. Therefore, when deciding which data are collected, researchers should consider the available information offered by the XR devices and software to verify the reliability of the study. In the stepping affordance experiment, one concern was whether the placement of the AR cue was reliable relative to the detected location of the ground plane. We recorded the position data of the AR gap and analyzed the mean altitude of the AR gap plane per participant across blocks, as well as after the ground had been re-scanned before the second block of trials. There was no significant difference between these altitudes, which means the placement of the virtual gap was reliable across contexts.

To determine reliability of measuring body dimensions with our remote app, we compared the actual measured shoulder width or maximum stride in the remote study to prior work. The mean of the shoulder width (maximum stride) in this study was 0.47m (0.85m), while the mean in prior lab work was 0.5m (0.88m). The similarity in measurements suggests that unsupervised experiments can provide data of suitable quality in a remote setup.

### 3.5 Application Deployment

Software development workload in designing these experiments definitely increased due to the distributed setting. However, remote experiments require compatibility of applications on different devices and operating systems. Furthermore, for user accessibility, a deployed version of the application instead of only a developer version needs to be supported. We used Google Play service and Apple Developer service for deploying our apps on the respective



**Figure 3: Instructions for measuring body dimensions as shown exactly to participants while performing the task.**

app stores of Android and iOS platforms. Even though apps for Experiment 1 were accepted to be published in the Apple App Store, the app for Experiment 2 was not accepted, as they found it was indirectly related to the pandemic. However, the app was able to be shared through internal testing and recruitment by using "TestFlight" to access the app.

## 4 SUGGESTIONS & CONCLUSIONS

Based on these two experiences, we have the following two reflections for conducting remote AR experiments:

- (1) Clear instructions are critical. Illustrative and pictorial instructions, such as figures, short videos, and visual interfaces are recommended as a component of the procedural explanation.
- (2) Email service is a reliable choice for data collection under the assumption that the internet connection is stable and the data file size is not too large. Automatically sending data is recommended, which also reduces stress in participants.

Our studies suggest mobile AR displays can be used to conduct experiments assessing spatial perception. These devices are convenient platforms on which to run remote studies. However, to achieve this goal, researchers must pay close attention to the clarity of experimental instructions as well as ensuring data sending mechanisms are reliable. Finally, designers should make use of the information provided by AR software for verification. Overall, our work provides a foundation for future studies investigating perception remotely with the use of mobile AR with smartphones.

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