# Communication and Collaboration Among DHH People in a Co-located Collaborative Multiplayer AR Environment

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## ABSTRACT

One of the most recent developments in augmented reality (AR) technology is co-located collaborative multiplayer AR environments, yet little research has been done to determine how communication and collaboration function in these settings. There is a gap in our understanding of whether these environments are currently accessible for Deaf and Hard of Hearing (DHH) people. Although technical aspects, such as design, implementation, accuracy, etc., of the technologies and users' behavior with assistive AR technologies, have been covered in plenty of prior literature, very few studies have paid attention to how DHH people communicate and collaborate in co-located collaborative AR environments. As an initial step toward addressing the gap in current literature, our ongoing research focuses on how DHH people communicate and collaborate in a co-located collaborative multiplayer AR environment. As part of our study, we conducted gameplay experiments and one-on-one semi-structured interviews with 17 DHH participants. In this piece of work, among the prominent themes that stood out in our findings, we further discuss communication and collaboration, specifically multi-modal communication (verbal and non-verbal) among users and how multi-modal communication affected their collaboration in the environment.

## CCS CONCEPTS

• **Human-centered computing** → **Accesibility**; **Mixed / Augmented reality**.

## KEYWORDS

Human-computer Interaction; Accessibility; Augmented Reality

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## 1 INTRODUCTION

Collaboration among multiple users simultaneously has raised research interests in augmented reality (AR) technology for a long time [8, 12, 23]. Additionally, AR has been described as, "an innovative media format that integrates virtual information into a user's perception of the real world," [16] and any other means of communication cannot match the richness of interaction the technology can offer [9]. Co-located collaborative AR environments have the potential to facilitate communication and collaboration among multiple users in a variety of scenarios [17, 22] including multiplayer gaming settings [3, 24]. However, to date, there is a scarcity of research focusing on whether co-located collaborative multiplayer AR environments can facilitate communication and collaboration while being similarly engaging among linguistic minority groups, such as Deaf and Hard of Hearing (DHH) people.

There have been a plethora of studies [2, 10, 25] where AR has been used as a means of facilitating assistive environments for DHH people. The majority of these studies, however, concentrated on the development, application, and accuracy of the technology or the interactions of DHH users with the technology itself. There are very few studies conducted to understand how DHH people communicate and collaborate in a co-located collaborative multiplayer AR environment. Additionally, the studies that have been conducted, which paid more attention to communication and collaboration aspects in AR environments, did not include DHH participants. As a result, there continue to be significant gaps in our knowledge of the communication and collaborative behaviors of DHH users in co-located collaborative multiplayer AR environments, which limits our comprehension of challenges DHH users might face in these environments and ways to address those challenges to make these environments more inclusive.

Our research is a primary step that seeks to address the gap in our understanding of the domain of communication and collaborative behavior of DHH people in a collaborative, co-located multiplayer AR environment. One of the main goals of our study is to explore

how DHH users communicate in a multiplayer AR environment when their primary modes of communication are different and how it affects their collaboration among themselves.

For our study, we conducted a gameplay experiment with 17 DHH participants, followed by semi-structured interviews. As the primary mode of communication, participants preferred either spoken English or American Sign Language (ASL). We analyzed the qualitative data using thematic analysis (TA) [5] and found some prominent themes regarding communication, collaboration, coordination of DHH participants in a co-located, collaborative multiplayer AR environment, and design implications for this particular environment from the viewpoint of DHH users. Among those, in this work, we will further discuss the communication and collaboration aspects, specifically, how users leveraged multi-modal communication (verbal and non-verbal) in a co-located collaborative AR environment, and how the modes of communication played a role before and during the game in such an environment. Furthermore, our study makes a contribution to our understanding of how DHH people communicate and collaborate in a co-located collaborative AR environment.

## 2 RELATED WORK

### 2.1 DHH People and AR

Mirzaei et al. [14] presented a system combining AR, automatic speech recognition (ASR), and text-to-speech synthesis (TTS), where the system takes speech from the speaker in real time, converts it into readable text, and shows it on the AR display. In another study by Guo et al. [7], they pointed out that prior studies mainly focused on script transcription, whereas they introduced a HoloLens-based AR prototype called *HoloSound*, where they used deep learning to classify and visualize sound identity and location along with speech transcription. They paid more attention to the UI and system exploration, along with the haptic feedback of the system. Vinayagamoorthy et al. [21] conducted a study, and their focus was to personalize television content for DHH people with an added sign language interpreter in the display area using AR. After briefly discussing the design and implementation of the system, they focused on the modes of interpretation preferred by the participants and the reasoning behind the preferences.

However, these studies have been conducted to make communication more accessible for DHH people leveraging AR, it is straightforward that the works paid more attention to the system's design, implementation, accuracy, or users' interaction with the system. Any kind of AR system or environment has not been used to point out how DHH users communicate with each other in AR environments, which further indicates the large gaps in our understanding.

### 2.2 Collaborative and Co-located AR

Simultaneous collaboration between multiple users in AR environments has been regarded as a significant research interest for a long time [4, 20]. The communication and collaboration aspects of co-located collaborative multiplayer AR environments, however, have received very little research attention. For instance, in a study about collaborative approaches to solving lines and angles-related problems using AR, Sarkar et al. [17] found that the majority of the participants (90.4%) preferred collaboration while using AR in learning activities. In another study, Wells et al. [22] found that, while AR can support collaboration in a co-located group setting, the lack of collaboration mechanisms can negatively impact the collaboration, and in that case, groups focus more on trying to find ways to overcome the issue. Furthermore, Bhattacharyya et al. [3] presented a model for designing shared AR experiences, and their research indicates the issues of developing such models and the major categories of interaction in a shared AR environment. In another study by Xu et al. [24], they designed a prototype called *Bragfish* as a part of their exploration, and further evaluated the prototype that illustrated how participants formed strategies for social play by using various cues (e.g., visual, aural, and physical) in a shared environment.

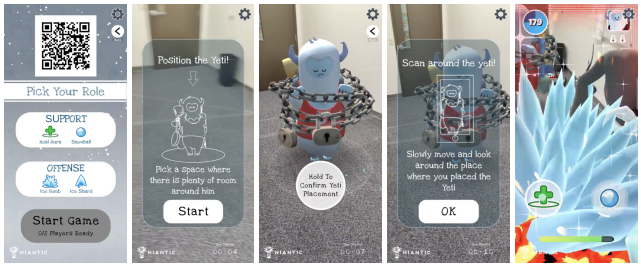
However, none of the studies we report in section 2.2 include DHH participants, despite the possibility that DHH people might have different needs for collaborative AR. This indicates a lack of inclusivity and further solidifies the gap in our knowledge about the communication and collaboration behaviors of DHH participants in co-located and collaborative multiplayer AR environments.

## 3 METHODOLOGY

Our study was divided into two main sections, 1) a gameplay experiment and 2) a one-on-one interview. We chose *Codename: Urban Legends*, a co-located collaborative multiplayer AR environment, for the gameplay experiment. According to Niantic, this is a glimpse into the future of AR and 5G networks [18]. We received early access to the game prototype for our experiment from Niantic. The game runs on 5G and is the only one of its kind where multiple players can interact with the same AR components from their own devices[15], allowing them a shared AR experience. The game uses a combination of tangible AR, shared AR, and co-located collaborative AR. The primary objective of the game is to cast spells to battle monsters and save imperiled allies [19]. There are two roles *offense* and *support*. The primary function of the *offense* role is to defend oneself and other players by dealing greater damage to adversaries. *Support*, on the other hand, acts as a healer by igniting a magical aura around themselves that can heal the damage done by enemies to themselves as well as anyone who enters the aura. Each session lasted for at most 240 seconds, and the AR components in the game are dynamic and need players to physically move or take action quickly.

### 3.1 Participants

We recruited 17 DHH players based on their responses to a set of questionnaires, which we later used as quantitative data to determine our demographic for the experiment. The participants self-identified as DHH, indicating that the level of residual hearing they had was not the same. They were in the age range of 19 to 32. Five of the participants were deaf, and the rest were hard of hearing; 14 of them mentioned spoken English as their preferred choice for communication, and the rest preferred written English and ASL. They were put into 7 groups in total; 3 of the groups had 3 participants, and the other 4 had 2 participants each.




(a) (b) (c) (d) (e)

**Figure 1: (a) Two roles of the game, (b) Host player trying to set down AR anchor (yeti) to start the game, (c) Finalizing the position of the yeti, (d) Scanning the surrounding before starting the game and (e) During the game, host player playing as *support*.**

## 3.2 Procedure

For recruiting our participants we used a two-step procedure. First, we distributed a registration form through email and flyers among college students, where we asked questions about participants' names, their pronouns, if they identified as DHH or not, and their familiarity with AR products. In the second step, based on the collected data, we reached out to participants who self-identified as DHH and asked them to let us know when they were available to participate in the gameplay experiment. We formed the groups solely based on the availability of the participants, where they did not have any scope to know about other players(s) in the group prior to the gameplay experiment. We implemented this anonymity in order to see whether the environment could encourage social interaction among DHH players in a manner similar to how it did for players who were not DHH [11].

Each group of the recruited participants played 5 rounds of the game, the first 2 of which took place in a smaller private area and the other 3 in a wider public one. We gave them a general overview of the game, technical issues they might run into (e.g., game lag, sudden shutdown of the game, failure to enter the game session) as the game was a prototype, and the experimental design; however, they had to explore the abilities and activities of each role in the game. They had a discussion period before each round to pick roles and discuss strategy. The choice of communication method they would employ both before and during the game was also left to them. We recorded their gameplay and the screens of their devices for further data references and took notes as our observational data. After the gameplay, they were told to pick a suitable time and mode (verbal or text-based) for a one-on-one interview, and based on their preferred mode, we conducted the interview over Zoom [1]. The interview we had with each participant acted as the main source of our qualitative data. Since the interview was semi-structured, we had the flexibility to adjust interview questions when necessary based on each interviewee and the gameplay experiment. Most of our interview questions were about the participants' personal experiences of the gameplay, issues that they faced while collaborating, communicating, and coordinating in the game, and design implications for addressing the issues from their perspective. We recorded the interviews as well to detect any data discrepancies.

# 4 FINDINGS AND DISCUSSION

We transcribed and cleaned the collected data from the interviews after cross-checking the video recordings with the participants' responses. We took note of the quantitative data that did not match with the recordings and participants' responses, such as localization time, duration of one round of gameplay, etc. We brought all the data and notes together on Nvivo, which served as a platform for generating sets of code by tagging the data so that reoccurring themes and patterns could emerge from it. We used TA, specifically, semantic and latent approaches for the analysis. Two of the most prominent findings about communication and collaboration were multi-modal communication between players and the relationship between communication and collaboration in the game in a co-located collaborative environment.

## 4.1 Multimodal Communication Between Players

Most of the participants (13/17) met each other for the first time, with the exception of two participants [player 04 and player 05] in group 02 and two participants [player 13 and player 14] in group 06 who were familiar with each other. They mentioned using verbal cues, gestures, and body language as their methods of communication before and during the game. They employed random and improvised gestures, which were not sign language since not all participants knew sign language. Participants who could communicate verbally did so using verbal cues before the game; otherwise, they used gestures and body language. Player 02 in group 01, who played with someone who could not communicate verbally [player 01, group 01], said,

> I tried to communicate verbally and with hand gestures. I noticed that one of the participants was definitely deaf, and I don't really know a lot of ASL. The only problem, I would say, was figuring out how to communicate so that everyone could understand. So I had to rely on either hand gestures or texting on the phone.

Several players (6/17) also mentioned this regarding communication before and during the game. The deaf players (3/17) were competent in ASL but did not know whether the other players were competent in it or not. And so for complex communication, such as selecting a role, discussing game strategy, and expressing their comprehension of the game roles during the discussion period before each round, they used a speech-to-text app to understand other players' verbal cues or typed their thoughts on their smartphone to communicate with other players. Player 01 in group 01, who was deaf, said later in a text-based interview,

> We did the gestures by pointing them out for each other, and sometimes we used texting to communicate.

All three deaf players mentioned that, as the game was fast-paced, they did not have time to type for communication, so they opted

out for gestures when they wanted to communicate with others during the game.

We can see that a co-located AR environment could foster social interaction, including verbal and non-verbal communication (e.g., hand gestures and body language), even if the players are strangers when they start the game, as agreed by several prior studies [6, 11]. Interestingly, we found that the main driver for utilizing multimodal communication was that participants were more concerned about whether other players could understand them than they were about using their own primary mode of communication. Furthermore, non-verbal communication played an effective and positive role in a co-located collaborative multiplayer AR environment, similar to social VR environments [13].

## 4.2 The Relationship Between Communication And Collaboration

Collaboration in the game was divided into two phases, 1) before the game and 2) during the game. Most of the participants (12/17) stated that they participated equally in the discussion before each round. While some participants may have been slightly more dominant than others, they would not describe this as 'aggressively leading the game'. However, we observed that players were collaborating less while playing the game, and the majority of the participants (10/17) confirmed that they were communicating less during the actual gameplay, despite the fact that more than half of them (9/17) mentioned, 'collaborating with others was the game's best aspect'. Player 15 from group 07, who played with two other participants who could communicate verbally, said,

> I don't really think there was that much communication necessary during actual gameplay.

Player 17 from the same group further commented,

> I'd say it [collaboration] happened in one of all five rounds, and again, we mostly communicated before each round [...] But asking for help, I think it only happened once in every play that we did.

When we asked about the reason behind this, one of the intriguing points that came up was the game design, lack of content, and lack of difficulty level of the game.

In both phases, communication played a vital role in determining the amount of collaboration. Most of the communication took place in the first few rounds before the game started. However, less communication was seen during the gameplay, and hence less collaboration took place in this phase. Players tried to overlook the technical issues when they ran into those and aside from that, in the last few rounds, the overall level of communication got even lower as the players became more independent and accustomed to the game.

# 5 CONCLUSION AND FUTURE WORK

Our research can be viewed as a primary stepping stone towards bridging the gap that remains in the field of DHH people's behavior in a co-located collaborative multiplayer AR environment. We recruited 17 DHH participants who gathered lived experience from gameplay experiments that we conducted and later shared their experiences in a one-on-one semi-structured interview. We acquired some intriguing initial findings from the gathered data that showed players were leveraging multimodal communication and the more they were communicating the more they were able to collaborate before and during the game in this particular AR environment. Although there were technical issues, the main cause of the decreased communication and collaboration over rounds was players becoming accustomed to the game's activity. We plan to extend our research and focus on a different co-located collaborative multiplayer AR environment for our next study. We will be able to identify more generalized and environment-specific challenges as well as solutions from the users' point of view from the findings of our future research that can further be used to design more inclusive co-located collaborative AR environments. Additionally, we want to recruit participants from more diverse backgrounds (e.g., age, occupation, and knowledge of AR) so that we can have a balanced number of participants from different demographic groups. We anticipate this will enable us to gather insightful findings in our future research.

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