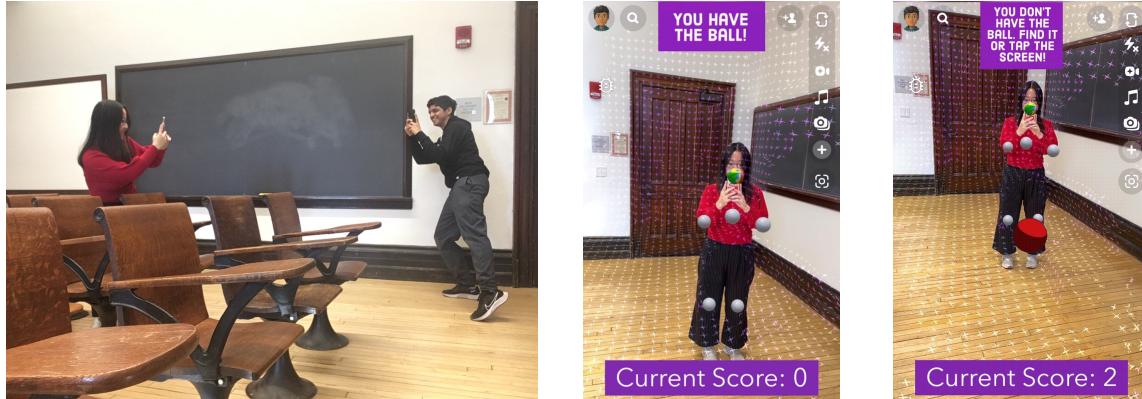


1           **Ball-AR: Fostering Playful Co-Located Interaction Through Environment-centric**  
2           **Physical Activity with AR**

3  
4           ARNAV KUMAR, Princeton University, USA  
5  
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7



23           **Fig. 1. The Ball-AR system in use. Ball-AR requires two players in the same physical space, and utilizes surface detection**  
24           **and body tracking for ball movement.**

25  
26           We present Ball-AR, an augmented reality (AR) game where two players in the same physical space attempt to hit each other with  
27           virtual dodgeballs overlaid on the physical world. Researchers have studied AR's potential for fostering co-located interaction and  
28           physical activity; however, they have not investigated the impacts of physical activity and physical environment on user experiences  
29           and interaction. We created an AR dodgeball game centered around encouraging physical activity and harnessing the physical  
30           environment. We then evaluated the game with five dyads to analyze the impacts of these design choices on the quality of gameplay  
31           and interaction between players. We found that physical activity and the shared physical space created memorable experiences and  
32           interactions among participants, although participants desired a more augmented and immersive experience.  
33

34  
35           CCS Concepts: • **Human-centered computing** → *Collaborative and social computing devices.*

36  
37           Additional Key Words and Phrases: augmented reality, physical activity, physical environment, co-located, interaction, design

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## 53    1 INTRODUCTION

54 In this paper, we discuss mobile AR game design by creating Ball-AR, an AR game inspired by dodgeball. Specifically, we  
 55 study the impacts of game design choices based on physical and social areas that we believe AR can influence positively.

56 Our first motivation is to promote physical activity and encourage movement. As a result of the COVID-19 pandemic,  
 57 physical activity levels have decreased an estimated 41% [11]. Conversely, in this same time frame, we saw a 75% increase  
 58 in gaming activity [5]. These behavior shifts motivated the idea to study how a game can encourage physical activity.  
 59 In addition, AR games allow the ability to move while playing, so a mobile AR game provides a great opportunity to  
 60 encourage physical activity.

61 The second motivation is to foster co-located interaction. Recent research has shown that mobile devices can  
 62 negatively impact communication and experiences between people in the same space [7]. However, mobile AR games  
 63 can be beneficial in fostering co-located interaction since they can facilitate communication and create fun, memorable  
 64 experiences [3]. Another benefit AR can have on co-located interaction is its usage of the physical environment, as  
 65 research has shown that the shared physical features of an environment can induce interaction between individuals by  
 66 interrelating them through a shared space [1].

67 We envision using AR to support physical activity in shared physical spaces. To do so, we created Ball-AR, an AR  
 68 game that builds on and extends previously researched design choices. We foster movement by requiring players to  
 69 move quickly, encourage social interaction by requiring sharing a physical location, and connect players physically by  
 70 utilizing the physical features of the common environment.

71 We evaluated how well Ball-AR deals with fostering movement, encouraging social interaction, and utilizing the  
 72 physical environment. We also study how the design choices affect participants' enjoyment of the game and their  
 73 interaction with their opponents.

74 We learned that the combination of a shared physical space and physical movement created enjoyable interactions and  
 75 that competition, hidden information, and the physical elements of AR were effective in increasing communication and  
 76 physical activity. However, participants did not feel connected to each other through the shared physical environment's  
 77 features and desired more augmentation rather than utilization of just the physical environment.

## 78    2 RELATED WORK

79 Recent research has shown that people are increasingly lonely and craving interaction [10]. Mobile technology may  
 80 add to this disconnect, as it can negatively affect communication and interactions in the same room [8]. In addition,  
 81 people have become increasingly sedentary [11]. Unfortunately, mobile technology may also influence this, as studies  
 82 have shown negative correlations between smartphone usage and physical activity levels[9].

83 With an estimated 5 billion people owning a mobile device, it becomes important to use these devices to encourage  
 84 interaction and physical activity [6]. As a result, more and more mobile technologies have emerged to do so. Regarding  
 85 fostering social interaction, video communication platforms like Zoom and Twitch have decreased loneliness-related  
 86 outcomes, and improved social interactivity [4]. For physical activity, wearable technologies such as smartwatches  
 87 or smartphones with mobile apps have positively impacted physical activity and weight control [13]. However, not  
 88 enough mobile technologies support both co-located interaction and physical activity.

89 To build our system, we focus on using AR, due to its known affordances of social interaction and physical activity.  
 90 Previous works have shown that AR can foster co-located interaction due to its usage of shared spaces and embodied  
 91 interaction. One previous work, Project IRL studied the influences of different design choices and features of mobile AR

games on co-located interaction, some of which informed the design of Ball-AR [3]. Another work, BragFish, studied specifically the impacts of shared virtual spaces on the physical and social interactions among players [12]. Both studies noted the potential benefits of AR games in fostering co-located interaction. However, these works did not center on combining physical activity and co-location in AR.

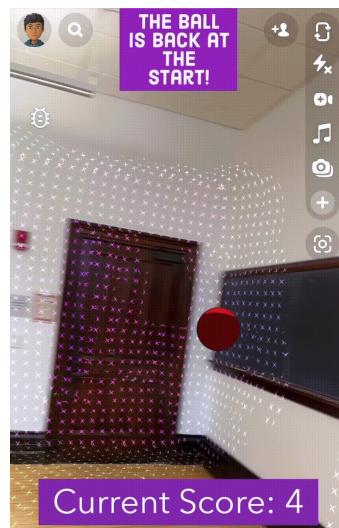
In addition, other works have shown the potential for AR to encourage physical activity. The mixed reality game VRabl immersed players in a virtual space and explored the impacts of different design features on inducing physical activity [2]. Game design choices from this study were used in Ball-AR. However, this study similarly did not research how inducing physical activity related to the quality of gameplay or interaction.

As a result, we study game features that encourage co-located interaction and physical activity with the goal of providing insight for future mobile AR game design. To do so, we design a mobile AR game, Ball-AR, and analyze how AR's usage of the shared physical space and embodied interaction can benefit co-located experiences for players.

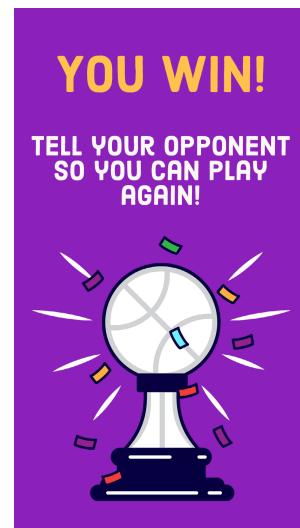
### 3 BALL-AR SYSTEM



**Surface Collection**



**Ball Recovery**



**Victory Screen**

Fig. 2. Description of different features within Ball-AR. Many features were designed to encourage movement or environment utilization.

Ball-AR is a multiplayer AR dodgeball game designed to be played by users in a shared physical space. To start the game, both players load the game on their mobile phones and stand in opposite corners of the room.

Players begin by first scanning the surfaces in the shared physical space. This entails walking around the room and pointing their mobile device at all physical surfaces, which are then captured by the lens. After collecting the environment, each user stands in the corner of the room, which is then deemed the starting spot. From this point on, each user now can throw their augmented ball at their opponent by tapping the screen. The ball can bounce off of any of the surfaces before hitting the opponent. If the ball hits three surfaces without hitting the opponent, the player must collect the ball to throw it again. If the ball hits the opponent without touching a surface, the player gets one point.

<sup>157</sup> In addition, the player gets an extra point for each surface hit before hitting the opponent (with a maximum of three  
<sup>158</sup> surfaces). For example, if the player hits two walls and then their opponent, their score increases by three. The first  
<sup>159</sup> player to reach ten points wins.  
<sup>160</sup>

<sup>161</sup> The game is designed to encourage physical activity and utilization of the shared physical environment to study  
<sup>162</sup> impacts on interaction. For example, since each user only has one ball, they must physically move around the room in  
<sup>163</sup> order to collect it. The aspect of competition adds a sense of urgency to the game, imploring users to rush to collect  
<sup>164</sup> their ball for a better chance at victory. In addition, the extra points awarded based on surfaces hit before hitting an  
<sup>165</sup> opponent are included to ground the users in the shared physical space and to focus on the physical features of the  
<sup>166</sup> environment.  
<sup>167</sup>

<sup>168</sup> Ball-AR was designed with Lens Studio and is accessible via the Snapchat app. More specifically, the World Mesh  
<sup>169</sup> and Body Tracking features within Lens Studio proved very useful in scanning a physical environment's surfaces and  
<sup>170</sup> determining when the ball was hitting a player.  
<sup>171</sup>

#### <sup>172</sup> **4 EVALUATION**

<sup>173</sup> We recruited ten university students through email to play Ball-AR in pairs. We then brought the participants to a  
<sup>174</sup> predetermined location with ample surfaces and no major obstructions. Each participant played a best-of-three match of  
<sup>175</sup> Ball-AR against another participant. Then, each participant was interviewed individually. We conducted semi-structured  
<sup>176</sup> interviews (see protocol in Appendix) with participants and focused on concepts related to overall enjoyment, physical  
<sup>177</sup> activity, environment utilization, and quality of interaction. The interview included questions such as "How did physical  
<sup>178</sup> activity affect your overall experience?" and "Did you make use of the ability to bounce the ball off physical surfaces?  
<sup>179</sup> What were your opinions on this feature?"  
<sup>180</sup>

#### <sup>181</sup> **5 STUDY RESULTS**

##### <sup>182</sup> **5.1 Participants felt shared physical space and movement fostered greater interactions, though some <sup>183</sup> desired a single-player experience as well**

<sup>184</sup> Many participants felt that being in the same room as their opponent created a more fun experience. *"It was cool to be*  
<sup>185</sup> *in the same space and it made the game more fun to play by being in the presence of the person you're playing against"*  
<sup>186</sup> (P6). In addition, the aspect of both players physically running around in the same room created enjoyable interactions  
<sup>187</sup> between players. *"The game was kind of a frenzy because I was just running around because I didn't want to get hit. [P7]*  
<sup>188</sup> *started laughing, probably because I was so hard to actually hit"* (P8). However, many participants voiced a desire to  
<sup>189</sup> have a single-player option as well to be able to play even when alone. *"Having a game with both single-player and*  
<sup>190</sup> *multiplayer would be nice. Multiplayer caters more to playing with friends but single-player could make more usable as a*  
<sup>191</sup> *mobile game and for exercise by myself"* (P3). While participants enjoyed the physical interactions with their opponents  
<sup>192</sup> and the shared physical space, many still viewed mobile games as a single-player experience.  
<sup>193</sup>

##### <sup>194</sup> **5.2 Hidden information increased communication and activity for participants**

<sup>195</sup> Within Ball-AR, players could not see each other's scores or see the opponent's ball, although they were in the same  
<sup>196</sup> room. As a result, participants communicated throughout the game, shouting scores and exclaiming when they hit the  
<sup>197</sup> opponent (sometimes to trick their opponent as well). *"I feel like the part of not knowing what other people had enhanced*  
<sup>198</sup> *the experience because it made the game really funny. We both kept yelling random numbers and I don't think either*  
<sup>199</sup> *Manuscript submitted to ACM*

209 *of us were even close to what we said*" (P4). In addition, not being able to see the opponent's ball encouraged greater  
210 movement. *"I had to guess which way the ball was going, so I kept moving since I figured the ball was aimed at where I was*  
211 *just standing*" (P5). Hiding details of the opponent from participants created a need for participants to communicate  
212 amongst themselves and encouraged more movement.  
213

### 214 215 **5.3 The competitive nature of the game induced physical activity among participants and encouraged** 216 **future play**

217 While there is no timer in the game, participants felt an implicit time due to the need to score before their opponent to  
218 win. As a result, many participants noted that the deeming of a winner and a loser at the end of a Ball-AR game led to  
219 greater movement and physical activity: *"I kept running after my ball to throw it again. Otherwise, I probably would have*  
220 *lost*" (P2). Other participants expressed their desire to play again after losing.  
221

### 222 223 **5.4 Participants felt that the blend of mobile AR and physical activity was fitting and memorable, though** 224 **potentially dangerous**

225 Participants expressed that AR made the game more enjoyable and felt that it allowed for features normal mobile games  
226 could not. *"I think AR should be geared towards actual real movements, not just sitting and playing with your finger. In the*  
227 *game, there is a physical element and it is like a sport"* (P6). In addition, the need for movement created a memorable  
228 experience within AR. *"A lot of AR is memorable but this one had movement involved and that made it cooler than other*  
229 *AR simulations where you're just looking at a virtual space"* (P10). However, some participants noted that the movement  
230 in the game and the small screen could potentially be dangerous. *"Someone could definitely bump into tables and chairs*  
231 *and stuff if they didn't really know the room that well. Normally, it's easier not to, but since you're running and looking at*  
232 *a phone, I could see that happening"* (P2).

### 233 234 **5.5 Participants did not focus on the physical features of the environment and desired more augmentation**

235 The ability to throw the ball off physical surfaces was included to ground the players in their physical environment and  
236 to foster belonging by connecting them through the shared space. However, most participants noted that they were  
237 more focused on other aspects of the game rather than the shared physical space. *"I wasn't really that aware of my*  
238 *surroundings because I was mostly looking for my ball or looking at [P2] to hit [them]"* (P1). Participants also expressed that  
239 the main use of the feature was for strategy and scoring rather than feeling connected to a certain physical space with  
240 their opponent. In addition, participants actually requested greater augmentation to enhance the physical environment.  
241 *"It would be cool if there were more cool things to throw off of in the room, like some virtual objects"* (P7).

## 242 243 **6 DISCUSSION**

244 Through these results, we can theorize at good and bad design choices for AR games, specifically when fostering  
245 physical activity and co-located interaction.

246 For physical activity, we discovered that giving each player one ball to follow around did induce movement. In  
247 addition, the competitive nature of the game fostered quicker movement due to the desire to win. In general, there  
248 seemed to be a sort of expectation among participants for AR games to expand on the capabilities of non-AR mobile  
249 games by encouraging movement. Most participants felt that the inclusion of physical movement and activity was  
250 fitting for AR and took advantage of AR's physical elements, hinting at the possibility that physical movement of some  
251 kind belongs in mobile AR games, although with more safety precautions.

261 In terms of co-located interaction, the use of hidden information fostered interesting communications among  
 262 participants. In addition, most participants enjoyed being in the same physical space as their opponent as it allowed  
 263 for these communications and created more enjoyable physical and social interactions. However, many participants  
 264 had the belief that mobile games such as this should have some sort of single-player capability. This may be due to  
 265 participants wanting to play on their own time without restriction or may be a result of the abundance of single-player  
 266 mobile games currently available.  
 267

268 We also noticed that physical activity and co-located interaction intersected greatly within the game. The encouragement  
 269 of physical activity created more memorable experiences for users and fostered physical interaction. Participants  
 270 had fun both running and seeing their opponent run frantically, and many recalled these moments afterwards as their  
 271 favorite moments of the game. These results describe a potential correlation between physical activity in AR games and  
 272 fun physical interaction between players that we encourage future mobile AR game designers to consider.  
 273

274 Lastly, many participants expressed the desire for more augmentation and greater immersion in the shared virtual  
 275 space. This speaks to the potential preference of users to escape or augment reality while playing an AR game, rather  
 276 than just interact with it. The features of the specific shared physical space did not make a substantial impact on  
 277 the interaction or belonging of participants, and perhaps a greater virtual presence could create a more memorable  
 278 experience for users.  
 279

## 281 7 LIMITATIONS

282 While we determined both benefits and challenges in mobile AR game design, there were some limitations. Our findings  
 283 come from a small, homogeneous group of participants, as all are college students with some interest in physical activity  
 284 games. Future research should explore a broader group of participants. Furthermore, all studies were conducted in the  
 285 same physical location. Future work should also experiment with different types of physical locations to expand this  
 286 research.  
 287

## 288 8 CONCLUSION

289 In this paper, we presented Ball-AR, an AR game designed to foster physical activity, co-located interaction, and physical  
 290 environment utilization. We designed the game using both techniques from previous studies and new designs to  
 291 encourage movement, increase communication, and ground users in their shared physical space. We then evaluated  
 292 the game with five dyads. From our results, we learned that the combination of a shared physical space and physical  
 293 movement created enjoyable interactions and that certain design features, such as competition, hidden information, and  
 294 usage of AR were effective in increasing communication and activity. However, participants desired more augmentation  
 295 and more usage of a virtual shared space.  
 296

297 Future works in designing co-located AR gaming experiences could expand on the results shown in this paper. For  
 298 example, future work could study more specific types of physical activity or study the impacts of greater augmentation  
 299 on co-located interaction. Overall, we hope future researchers continue to explore mobile AR games and their ability to  
 300 positively impact interaction and health of players.  
 301

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## 341           A INTERVIEW PROTOCOL

342 Participants followed along the protocol shown below:

- 343 (1) Each of the 10 participants was asked to meet at a predetermined location, where they were told about the  
344 study and shown the instructions to the game.
- 345 (2) Participants were separated into five groups of two. Each group played a best-of-three match (first to two wins)  
346 of Ball-AR.
- 347 (3) After the match ended, each participant was individually interviewed. They were asked the following questions:  
348           • What are your thoughts on the Ball-AR experience? Would you play again?  
349           • What was your favorite feature of the game? What was your least favorite feature of the game?  
350           • Did you enjoy the aspect of playing against another person? Would you have preferred a single-player  
351 game?  
352           • Did you like the competitiveness of the game? Would you have preferred a collaborative game?  
353           • Did playing the game in the same room as your opponent make the experience more enjoyable? Would  
354 you have preferred a virtual/remote version?  
355           • Did you move at all while playing Ball-AR? How did physical movement affect your overall experience?  
356           • Did you make use of the ability to bounce the ball off physical surfaces? What were your opinions on this  
357 feature?

- 365     • Did the use of a mobile device make the game more enjoyable or less enjoyable? Why?  
366     • Would you have preferred sharing a ball with your opponent rather than each having your own?  
367     • Did you encounter any dangers while playing Ball-AR?  
368     • Do you have any general suggestions for Ball-AR and its next steps?

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