A Look at the Effects of Handheld and Projected Augmented-reality on a Collaborative Task

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ABSTRACT

This paper presents a comparative study between two popular AR systems during a collocated collaborative task. The goal of the study is to start a body of knowledge that describes the effects of different AR approaches in users' experience and performance; i.e., to look at AR not as a single entity with uniform characteristics. Pairs of participants interacted with a game of Match Pairs in both handheld and project AR conditions, and their engagement, preference, task completion time, and number of game moves was recorded. Participants were also video-recorded during play for additional insights. No significant differences were found between users' self-reported engagement, and 56.25% of participants described a preference for the handheld experience. On the other hand, participants completed the task significantly faster in the projected condition, despite having performed more game moves (card flips). We conclude the paper by discussing the effect of these two AR prototypes in participants' communication strategies, and how to design handheld interfaces that could elicit the benefits of projected AR.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; *Collaborative interaction*; *Empirical studies in HCI*;

KEYWORDS

Mixed-reality, augmented-reality, AR, handheld displays, shared displays, collaboration, handheld AR, projected AR

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1 INTRODUCTION AND RELATED WORK

Despite the seemingly over-night success of augmented reality (AR) video-games (e.g., Pokemon Go[1]), AR systems have been the focus of HCI research for the past 50 years. Traditionally, AR systems add a layer of digital information over the real world in real-time; and they do so in three ways [2]. The first is through optical see-through, in which digital information is displayed on a translucent head-mounted display [32]. The second is through video see-through, in which digital information and video from the real world are combined and displayed in tandem. The resulting augmented world can be consumed through either head-mounted [9] or hand-held displays [34]. Finally, AR systems can also rely on a projector to overlay digital information directly onto the physical world [22].

Recent developments in handheld devices and high definition (HD) video capture have contributed to an increased availability of AR technologies, especially the latter two approaches: handheld and projected AR. A common implementation of handheld AR uses a directional approach to decide where to display information, capturing the user's position and viewpoint through GPS, motion sensors, and/or a compass [3], or through object and surface tracking [10] — all of these sensors are readily available in most smart phones. On the other hand, projected AR systems tend to rely on an optical approach when deciding where to display information: either through visual markers that, placed in areas of interest, serve as anchors for digital information and controls [30]; or through computer vision techniques that estimate those areas of interest [27]. Together with open-source optical solutions such as the NyARToolkit[2], a projected AR system can now be put together for as little as $100 (HD projector and camera).

But despite their increasingly pervasive nature, few studies have looked at the impact of different types of AR systems in the user experience, especially the effects of handheld and projected AR during collocated collaboration. While exciting systems have been development in this domain [1, 4, 11, 17, 29], comparative studies in the area tend to contrast AR to other types of interactive systems. Examples include comparative studies that describe how AR interfaces might be better suited for collocated collaboration than generic computer interfaces. This is because they are less likely to introduce artificial seams between the real world and the shared digital task [15], and thus more likely to enable natural communication between collaborators [7, 8, 33] — including non-verbal communication [5, 20]. Other examples describe how remote collaboration through AR can increase users' sense of presence when compared to a desktop setup [6]; how users can achieve more effective collaborations in AR than in similar VR counterparts [19]; and the positive effects of AR in collocated collaborations in the classroom [35]. Finally, Clergeaud *et al.* [12] discusses how users in different positions of the mixed-reality continuum [23] can collaborate effectively.

[1]https://www.pokemongo.com/

[2]http://nyatla.jp/nyartoolkit/wp/

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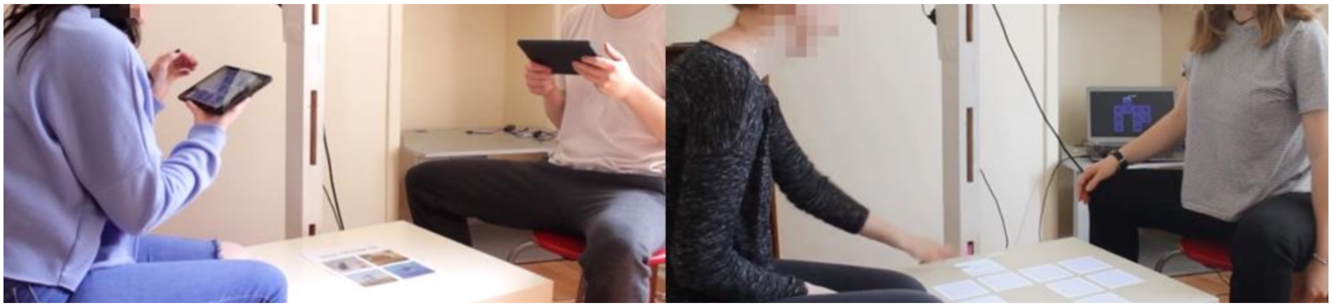

Figure 1: Participants interacting with the AR Match Pairs game in both study conditions: handheld (left) and projected (right).

We contribute to this body of work by presenting a first comparative study between two types of AR systems (handheld, projected) in users' experience and performance, during a collaborative, collocated task between pairs of participants.

2 AUGMENTED-REALITY MATCH PAIRS

The collaborative task selected for this paper is based on the traditional memory game of Match Pairs. In this game, a single player faces a N-sized grid of paired cards, which start facing down at randoms positions in the grid. In each turn the player is allowed to flip two cards - if these do not match, the player flips them back down. The game ends when all cards are facing upwards, or when the player runs out of time or turns. This game was selected due to its simple rules and interaction, requiring very little practice time from participants. To turn the game into a collaborative task, we altered the rules so that the game is played by two players, each responsible for flipping a single card each turn (players take turns flipping the first card). Two versions of the game were developed (see Figure 1), supporting handheld and projected AR.

The **handheld AR** version of the game was developed using Unity[3], and targets Android devices. AR functionality was supported through Vuforia[4], which displayed the card game over a single marker captured on the handheld devices' camera. The game state was synchronized between players/devices using Photon[5], and player input was captured as standard input touches on the device's display. The **projected AR** version of the game was developed using the Processing programming environment[6], and runs on a standard computer. Output was provided via top-down projection, and user input was captured via a webcam that looked for colored-caps (red, green) placed on participants' index fingers (similar to [25]). Finger tracking was achieved through Processing's standard video library, which captures the RGB value for each pixel in view. A card is flipped if: (1) the color of a pixel matches the color of one of the two colored-caps used for selection (Euclidean distance < 10); (2) this lasts for a short period of time (~700ms); and (3), the pixel is within the card's boundaries.

[3]https://unity3d.com/
[4]https://unity3d.com/partners/vuforia
[5]https://www.photonengine.com/en/PUN
[6]https://processing.org/

Figure 2: A closer look at the AR interfaces for the handheld (left) and projected (right) versions of the Match Pairs game. Each animal is displayed as a 3D model in the handheld condition to match common implementations in this domain.

3 USER STUDY

To explore some of the effects of the two implementations of our collaborative AR game, we conducted a study with eight pairs of participants (9F), aged between 19 and 25 (M = 21.5, SD = 1.8). These were paired with friends/acquaintances to facilitate communication.

3.1 Experimental Setup and Design

The experiment was conducted in a quiet room, following a within-subjects design with two conditions: the *handheld* and *projected* versions of our AR game. Participants in the handheld condition interacted through a NVIDIA SHIELD K1, an 8" tablet. In the projected condition, a webcam (720p, 30Hz) and projector (1080p, 60Hz, 2000lm) were fixed 125cm above the game table (55x55cm). In both conditions, participants faced a 4x4 grid of animal-themed cards, which position was randomized at the start of the game. To adhere to the aesthetics of common handheld AR experiences, each animal is displayed as a 3D model in the handheld version of the game (instead of simply printed on the card's face) — see Figure 2.

3.2 Procedure and Metrics

Each session started with a brief explanation of the study, and by capturing participants' demographics. To minimize interference during play, they were then instructed to sit at opposite sides of the game table, and asked not to stand up while the game was taking place (see Figure 1). At the start of each game (counter-balanced), participants took a couple of minutes to familiarize themselves with the input technology. Once the game was completed, they were asked to complete the User Engagement Scale short form (UES-SF) [28], which measures self-reported user engagement. General metrics such as game duration, number of card flips, and preference were also captured. Finally, participants were video-recorded during play for additional insights.

3.3 Results

The mean results for the UES-SF are presented in Table 1. This includes the results from paired t-tests, which show no significant differences between the two versions of the AR game in all four engagement sub-scales. Table 2 presents the mean results for game duration and number of card flips per game. These are significantly different between our two implementations, with participants performing more card flips, but finishing the game quicker in the projected version of the game. The paired t-test for game duration was completed after a single (positive) outlier was replaced by its nearest neighbour (plus one unit). This corresponds to a pair of participants that took 962s to complete the game in the handheld condition (more on this in the video analysis subsection below).

Finally, *nine* participants reported a preference for the handheld experience, describing it as easier to use, more intuitive, and more familiar. *Six* participants reported preferring the projected game due to its novelty, being more innovative, and because it made it easier to communicate card positions to their partners. *One* participant reported no preference between the two versions of the game.

3.3.1 Collaboration strategies. Informal video analysis allowed us to extract different collaboration strategies employed by participants during handheld play, where the lack of a shared display made non-verbal communication harder (e.g., pointing at which card the other player should flip to generate a match). We observed four distinct strategies to communicate card positions to a partner. In *game-reference*, participants would describe card positions in relation to other cards already flipped, such as "the one above the shark". In *grid-reference*, participants would code each card position with a single number (1 to 16), or with a letter (columns) and number (rows). In *player-reference*, participants would describe card positions in relation to themselves or their partner's, such as "the card in the row closest to you, (...) the second from the left". And finally, in *space-reference*, participants would describe card positions in relation to the room itself, e.g., "the card (...) closest to the door". These would often accompany a pointing gesture.

Participants were observed changing approaches during the game, especially between player- and space-reference strategies. More than once, participants had to be reminded to remain seated, especially if these strategies were not enough to elicit the correct response from their partners. One pair of participants never managed to agree on a referencing strategy, and took more than twice as long to complete the task than the average pair of participants.

4 DISCUSSION AND FUTURE WORK

We have selected and implemented our study conditions to reflect arguably the two more commonly available AR systems today: a mobile application in a portable, screen-based device; and a shared projection often seen in museums and playgrounds. We do this with the goal of better understanding the benefits and limitations of each approach in the context of collocated collaboration — one of the most popular application areas for AR. Because these two types of AR systems present very different constraints in terms of development and deployment — one being deployed in users' mobile devices and requiring a motion sensor and camera [10]; the other requiring a fixed setup with clear light-of-sight to the interaction area — our insights are particularly useful to anyone looking to adopt AR in shared, collaborative scenarios (e.g., classroom).

Table 1: Mean results for the User Engagement Scale short form (UES-SF) on a 5-point Likert scale (higher is better), including paired t-tests (df = 15). Standard dev. in brackets.

UES-SF	Handheld	Projected	t, *p*
Focused attention (FA)	3.75 (0.66)	3.31 (0.70)	-1.71, .107
Perceived usability (PU)	3.15 (1.17)	3.60 (0.77)	1.71, .107
Aesthetic appeal (AE)	3.83 (0.69)	3.71 (0.58)	-0.88, .393
Reward factor (RW)	3.29 (1.00)	3.29 (0.70)	0, 1
Overall engagement	3.51 (0.64)	3.48 (0.36)	-0.16, .878

Table 2: Mean results for game duration (in seconds) and number of card flips, including paired t-tests (df = 7). Significant differences in bold; standard deviation in brackets.

	Handheld	Projected	t, *p*
Game duration	427.88 (233.47)	222.38 (44.40)	-2.83, **.025**
Card flips	33.50 (10.47)	44.50 (9.05)	3.73, **.007**

Our first finding is that participants' self-reported engagement did not vary significantly between conditions. This is despite both prototypes having quite different means of interaction (e.g., *perceived usability*), and presenting the game cards in 3D and 2D (e.g., *aesthetic appeal*). Likewise, preferences were evenly split between the two conditions, with 56.25% of participants describing a preference for the handheld experience. Interestingly, several participants justified their choice by describing the handheld experience as more intuitive and familiar, despite the projected condition being developed to resemble more closely a physical, real game of Match Pairs. This not only speaks to the adoption of mobile AR, but reinforces Hornecker *et al.*'s [14] critique of the idea that interaction directly rooted on physical metaphors can automatically leverage users' prior knowledge of interacting in the real-world. In sum, while these initial results might suggest that the choice between handheld and projected AR has little impact in users' experience during collocated, collaborative tasks, participants' performance results suggests a more complex relationship.

Participants completed the task significantly faster in the projected condition, which can be explained by a system that provides a better interface to the task, and/or better supports collaboration between users. User feedback and UES-SF results, especially the FA and PU sub-scales, suggests that participants did not consider one interface to be particularly more usable than the other — if anything, the handheld system was often described as more intuitive and familiar. As such, we would argue that the handheld condition had a negative effect on participants' collaboration. On one hand, the digital cards in the handheld prototype shared some of the properties of real, physical cards, such as supporting reference frames for communication [24] (as described in participants' collaboration strategies). On the other hand, this seems to position the handheld condition closer to a remote collaboration scenario, where the use of spacial references is commonly observed in detriment of embodied instructions (e.g., pointing) [26]. Not only that, we suggest that the use of individual (and private) viewpoints, described as key to collaborative AR [33], created a seam between the task and communication spaces — similar to what is observed during collocated collaboration through standard PCs [7]. This tells us that the *independence* and *individuality* features of collaborative AR described in [33] are task-dependent; arguably more suited for tasks requiring visual search or spatial manipulation — this should be explored in future work, including how these limitations are shared with AR systems built for head-mounted displays.

Furthermore, participants performed significantly more actions (card flips) in the projected condition, despite having completed the task in a shorter time. One explanation for this is the use of card flips as a form of epistemic action [13, 18]: actions performed to offload some of users' cognitive load onto the task itself. Kirsh *et al.* [18] describes how expert Tetris players will look for an ideal location for a piece by continuously rotating it on its way down, instead of performing this rotation solely mentally. By performing quick and numerous card flips, our participants were likely engaging in a strategy described in [13] as *artifact trial-and-error positioning*, which would reduce the task's memory demands, but requires a higher degree coordination better supported in the projected condition. While previous work has broadly described how AR is likely to lower cognitive load during collocated collaboration [5], our results suggest that much work is needed to fully quantify the impact of different AR systems in users' epistemic strategies.

Finally, we would like to discuss how future handheld prototypes could be implemented to improve collocated collaboration in AR, especially to facilitate non-verbal communication between collaborators. First, pointing at interface elements by pressing on the display should highlight these to other users. This could also be achieved passively through portable eye-trackers such as the Tobii Pro X2-60[7] or the Pupil Pro [16]. Similar techniques have been demonstrated to improve collaboration efficiency [19]. Second, users should be able to momentarily share their viewpoints with others. This could be done manually by, e.g., tagging the back of each handheld device with a marker that would allow users to peek into that viewpoint; or automatically, by, e.g., offering to show the view of the user who's speaking. This type of dynamic task orientation should not only have a positive effect on user's referencing strategies [21], but similar approaches have been shown to improve collaborative and social interaction [31].

5 CONCLUSION

This paper presented a comparative study between two popular AR systems (handheld, projected), and discussed their effects on users' experience and performance during a collocated, collaborative task. Our goal is to motivate a body of knowledge that describes the different affordances and benefits of different types of AR systems in this domain. This is especially important as AR systems have quite different development and interaction constraints, ranging from a simple mobile application with minimal external dependencies (with the exception of the occasional paper marker); to head-mounted displays equipped with hand-tracking or voice-recognition; to projection systems that require a fixed setup and are harder to scale. The next steps for this work should look at quantifying collaboration in different types of tasks (e.g., tasks requiring spatial manipulation such as a jigsaw puzzle), and different types of input systems. These would include tangible AR systems where users interact not by tapping, but by manipulating real objects (e.g., Match Pairs with physical cards); or AR systems built for head-mounted displays.

[7] https://www.tobiipro.com/product-listing/tobii-pro-x2-60/

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