Comparative Study of Body Doubling in Extended Reality

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(ABSTRACT)

Body doubling is a mechanism that lets individuals work alongside someone on a monotonous task that they might not be able to focus on when they work alone. The person they work alongside is called a body double. It could be considered similar to co-working, but it gives individuals the freedom to work on anything that they want without feeling obligated to interact with the other person. This research aims to understand if body doubling is helpful to the users and how mixed reality body doubling can be a better addition to the existing mode of in-person and video-call based body doubling. In this work, we have recruited 40 participants to perform a user study where we have done a between-groups comparative study between a no body-double, in-person body double, a video-call based body double, and a mixed reality body double modes. Through these studies, we try to analyze if body doubling is helpful, and if so, which mode the participants are more inclined towards. The work also presents a few suggestions for future improvements.

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(GENERAL AUDIENCE ABSTRACT)

Body Doubling, defined here, is in the context of a productivity strategy where a person is present beside an individual when they are working. This way, when the individual is working on a monotonous task, a person beside them would make them motivated to focus again. The person helping in body-doubling is called a "Body Double". This uses the concept of accountability that is felt in the presence of someone. Even though it seems similar to widely popular co-working, where job professionals share an office space to work together, in body-doubling, there is no interaction with the body-double, and in most cases, the two individuals might not be working on the same task. This research aims to understand if body doubling is helpful to users. In this work, we have recruited 40 participants to perform a user study where we have done a between-groups comparative study between a no body-double, in-person body double, a video-call based body double, and a mixed reality body double modes. It tries to show how mixed reality body doubling can be a better addition to the existing mode of in-person and video-call based body doubling. Through the user studies, we try to analyze if body doubling is helpful, and if so, which mode are the participants more inclined towards. The work also presents a few suggestions for future improvements.

Dedication

I would like to dedicate this work to everyone who is interested in research and want to contribute something to the field of education.

Acknowledgments

I would like to thank my parents, who supported me throughout my education and made it possible for me to come this far. I would like to thank my advisor, who has been very patient and supportive of my work until the end. His constant support and help made it possible for me to complete my thesis. I would like to thank all of my family and friends, who have been very encouraging of me throughout my research. And special thanks to my friend, who introduced me to the term based on which I started my research. Lastly, I would like to thank the participants who have been a part of my user study.

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List of Abbreviations

ADHD Attention-deficit/hyperactivity disorder

MR Mixed Reality

XR Extended Reality

Extended Reality (XR) is a term used to refer to Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and everything in between.

Mixed reality is a term used to describe the blend of real-world and computer-generated environments. Real and virtual objects may co-exist and interact in real-time. They can be viewed using a mixed-reality headset.

Attention-deficit/hyperactivity disorder (ADHD) is one of the most common mental illnesses affecting children. Children with ADHD may struggle to control impulsive actions, pay attention, or be highly active.

Chapter 1

Introduction

Body doubling is a strategy that involves having a supportive individual present during an activity in order to help the person stay focused on a task. Typically, the supportive individual will engage in a similar task or activity alongside the person they are supporting. Sometimes, the body double could just be sitting and listening to music, but their mere presence helps users to stay anchored and focus on their task. Body doubling can be particularly helpful for individuals who struggle with self-regulation and attention during a task. A body double can help the individual focus on the task, avoid distractions, and complete the activity more efficiently by providing a sense of accountability and support. It gives individuals a sense of accountability that comes when they feel someone is observing them.

Body doubling is mostly done in person, where the body double is present beside the individual doing the task. In recent times, there have been a number of applications that are facilitating users to take part in online body doubling. Most of these applications generally connect users who want to participate in body doubling through video calls. Interested individuals can register for the application and schedule sessions when they want to work. Most applications connect a group of individuals rather than pairing just two users. Participants introduce themselves, set their goals, and start working with breaks in between. A few examples are Flown [41], Flow Club [46], Caveday [49], and so on. Most of these applications charge a minimum fee to book sessions after the free trial period.

1.1 Motivation

These applications have become popular among individuals with Attention Deficit Hyperactivity Disorder (ADHD) [14] community. Individuals diagnosed with ADHD may experience difficulties maintaining focus, regulating impulsive actions, or being overly active. That also manifests in interacting with computer and related technologies where such individuals are more likely to experience sensory overload and can be more susceptible to cybersecurity exploits [24]. Research shows that while ADHD is not curable, it can be effectively managed, and certain symptoms might improve as the kid grows older. Although there is no scientific evidence that the body-doubling technique helps individuals with ADHD, many individuals believe that the technique helps them to focus and complete their work.

They are also being used by numerous students and employees who work remotely. With the COVID-19 pandemic, many institutions have shifted to remote modes. With this, there have been great impacts on the educational system [9] as well as professionals working remotely [15]. It was as hard for the population involved as for the system to transform everything into online mode. In some way, it has given everyone the luxury of accessibility to resources and the flexibility to work from anywhere. Even after the situation has improved, many individuals are still opting for remote work and education if given the choice.

But this comes with a few drawbacks. When doing something alone, there are high chances of getting laid back after some time, and it is easy to lack a sense of accountability, leading to procrastination. Even though we have numerous deadlines, pushing things past the deadline is easy. Once we start doing that, it is very easy to get into the habit of procrastinating things till the last minute. This will affect a lot of personal stuff and cause mental stress in the long run. Also, with many distractions, such as social media and streaming services, staying on top of things when working alone at home is difficult.

In order to be more productive and accountable while working remotely, many individuals have started using these body-doubling platforms [26]. They have found these online body-doubling apps to be extremely helpful. They could be considered similar to Coworking spaces [16]. Coworking spaces are shared workplaces used by knowledge professionals, primarily freelancers. These spaces are office-renting facilities where workers rent desks and Wi-Fi connections, and they are places where independent professionals live their daily routines side-by-side with professional peers, largely working in the same sector. Coworking is characterized by four common values: collaboration, openness, community, and sustainability. Although coworking seems to be aimed toward productivity, it is narrowed primarily to the use of professionals working for a company. It is a special kind of office space where all employees work in similar areas, in fact collaborating if they work for the same institution.

However, body-doubling gives more freedom to the type of work and the space people use to work in. It does not limit itself to just office work or student assignments. Here, individuals can work on their personal goals or work, such as paying bills or writing a novel. It is a mechanism to provide space for people to work on tasks they find difficult to complete when working individually. It involves little to no interaction between the participants. This helps individuals who like to work in a calm environment but get distracted when they are alone.

Body-doubling is an extremely useful concept, but there is a dependency on another person for this. An individual needs to coordinate with another person for a time and place if they are meeting in-person to work together. So the schedule for work depends a lot on the availability of the other person. When the person is already struggling to focus and work, this whole procedure can be very exhausting. The person might actually get no work doing all this procedure.

In such a case, online applications that facilitate video call-based body-doubling and easily schedule time are good alternatives. They make the whole process of finding a body double very easy at the times the person wants to work. So, the person can work from the comfort of their house or any place of preference and does not have to feel obligated to rely on someone to complete their work. Since all the other participants on the platform are also experiencing a similar problem, they can be assured that no one will judge them. Additionally, the platform would be more structured and monitored, so the individual does not need to be scared or worried about internet strangers. This helps to prevent mutual distractions between the participants.

With the rapid growth in the use of body-doubling and multiple online applications being introduced, it is important to research how this mechanism works in an XR environment. There have been numerous VR and MR projects for coworking to facilitate education and research [60]. But no work in XR is aimed at body-doubling particularly. In this work, we have designed an MR prototype that mimics the concept of body-doubling in XR. We aim to understand how users perceive body-doubling in different modes such as in-person, over a video-call and in MR. We also aim to compare it with the no body-double mode and analyze the effectiveness of body-doubling based on the opinions and behavior of the participants.

1.2 Overview of the study

As part of the research, an email was sent to the university email list servers, and interested participants over 18 years old were recruited for the study. 40 participants were assigned sequentially "between groups" in the order of no body-double, in-person, video-call based, and MR body double modes. During the task, they were asked to put on a gaze-tracking device called the Tobii eye tracker [55] during the first three modes and MR Hololens [36] in the last mode. They were asked to perform a task as part of the task after signing the consent form. At the end of the task, the participants were asked to fill out a questionnaire consisting of NASA TLX and SUS surveys, with a few additional custom questions to understand the participant's attention during the task.

Participants could leave the study at any time if they did not want to continue. All their survey responses, gaze data, task completion level, and accuracy were analyzed. While the NASA TLX and SUS surveys gave an idea of the participants' opinions about the task and system in general, the additional custom questions gave a better understanding of the participants' attention and interest during the task. The participant's gaze direction aids in determining how much time they spent working on the task or whether they frequently became distracted by anything else, including the body-double. Task completion and accuracy were measured to determine the participants' performance levels during the study.

Chapter 2

Review of Literature

An initial search on this topic resulted in not many academic paper results. There were a few blogs, news articles about body doubling, and online applications that facilitated this technique. Technologically mediated services for body doubling have subsequently been developed. However, there is not any other academic research on the topic besides a study by Edge et al. [12], in which most of the participants admitted to using this method before they knew what it was called. Individuals usually use body doubling in a café or on YouTube. They use it for various tasks, such as studying, doing dishes, and exercising. They admit that engaging in body doubling generates momentum and helps maintain focus on the work at hand.

Many individuals don't prefer to work alone. Working alone requires a lot of discipline and focus to avoid distractions and complete the task on time. Sometimes, they prefer to work alone to concentrate on their task or just to have some alone time. But at the end of the day, they need people around them to keep them motivated to keep working. At the same time, many people don't like working in teams, as it can get frustrating sometimes when there is a clash among team members or when there is a communication gap between team members.

One solution for this problem is the concept called Body Doubling, where the user works in another person's presence. They might not necessarily help with the work being done, but they might work on some tasks that may or may not be the same. Here, individuals with similar mindsets or who are working on similar tasks can work together in parallel on their own tasks, with as minimal interaction as possible. This helps to push users to work when they notice that the other person is working. It also helps keep them grounded so they can complete their work without distraction. Many people might be using this concept without knowledge of its existence. This mechanism has been widely used among individuals with ADHD in recent times [51]. There is no proven research stating that body doubling improves the condition of a person with ADHD, but individuals with ADHD say that it helps them focus better and complete their work.

Furthermore, there are many scenarios where we use body doubling without actually realizing it.Multiple ideas are similar to Body doubling, such as activity buddy, pair programming, study buddy, etc.

2.1 Research Questions

Based on the initial research, it was decided that we needed to do an extensive search with related terms. The following four research questions were defined. We use these questions as a basis for the systematic literature review.

RQ1: Is Body Doubling really helpful?

RQ2: What does body doubling mean in MR? How is it different or similar to body doubling in the real world?

RQ3: What are the challenges in the real world, and how can they be improved in MR?

RQ4: What are the challenges of implementing body doubling in MR?

2.2 Systematic Review

PRISMA methodology was used to conduct the systematic review [31].

2.2.1 Paper collection strategy

In order to understand the previous works in the field of Body Doubling, papers from different sources were researched. Since there were not many related works, similar works were researched. In this process, around 383 papers from forums such as ACM(110), IEEE(71), ScienceDirect(125), Scopus(28) and VT Libraries(49) were collected (Figure 2.1. The different search queries used to lookup papers were: 'body doubling', 'body doubling for adhd',' accountability partner', 'task partner', 'productivity partner', 'immersive co-working spaces', 'immersive collaborative spaces', 'co-working spaces in mixed reality', 'collaborative spaces in mixed reality', 'pair programming', 'study or activity buddy'. These terms were used with different variations in each of the source's advanced searches. The top 20-25 papers for each search query were chosen initially. Sometimes, when there were no relevant papers, the search results were ignored.

It is interesting to note that no papers include the term 'body doubling' as a productivity technique in all of these sources. Even a general Google Scholar search resulted in no useful results. So the remaining papers were screened based on their similarity to body doubling. All the search terms were decided based on initial research of activities that included working in the presence of other people to improve productivity.

Out of the 383 papers, after initial screening and removing duplicates (20 papers), 97 papers were filtered out. A few other papers (23) and websites were included to get better information about Body doubling or any required tools or information referenced while designing or

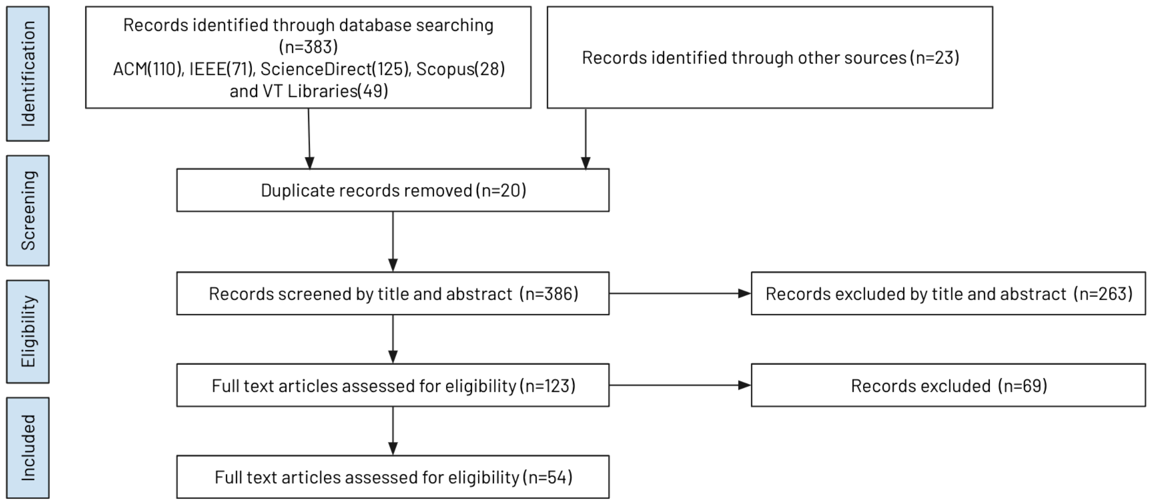


Figure 2.1: Systematic Literature Review using PRISMA.

analyzing the study. For this process, software tools named Zotero and Rayyan were used. Zotero is an extension to download a snapshot of the research papers, including the title, abstract, and publication details. This helped to gather and store all the initial relevant papers in one place. Rayyan is an AI-powered tool for Systematic Literature Reviews. This helped to filter and search papers based on keywords and timelines easily. It also helped to include and exclude papers or tag them with a label. After a review of these papers, 54 papers were chosen.

2.3 Background

Study with Me (SWM) [30] videos, which feature people studying without social components or informational content, have gained popularity on video-sharing platforms like YouTube. Researchers analyzed 30 videos and conducted 12 interviews with viewers to understand their motivation and viewing practices. They identified a three-factor model for shaping a satisfactory studying experience: expected effect, internal state, and external ambiance.

Viewers self-regulate their learning through watching SWM videos to improve efficiency even when studying alone at home. The study suggests that watching SWM videos could be viewed as a new form of self-regulated learning (SRL) where one tries to understand and control their learning environment. The findings are relevant during the global pandemic, as studying environments have drastically changed.

The studyby Lee et al. [30] explores the use of Study-Friendly Video videos as a study environment for students during COVID-19 restrictions. The videos provide emotional support, a study-friendly atmosphere, and cost-effectiveness by allowing users to control their environment and find motivated study partners. They also help reduce distractions from smartphones and enhance the study experience. The viewers can adjust their presence to create a study-friendly environment, balancing the desire for concentration and extended study time. The study also explores the impact of video feedback on instructors' social presence in blended courses and the role of technology in education, particularly in remote collaboration. The authors emphasize the importance of considering the role of technology in education and the potential benefits of incorporating it in education.

Study with Me (SWM) [22] is a popular type of in-real-life (IRL) streaming among students, and research suggests that parasocial interaction with streamers can potentially increase learning productivity. A two-week field study was conducted to investigate the impact of SWM content on participants' learning productivity. The study found that three ways parasocial interaction with streamers influenced participants' learning productivity were encouragement/companionship, a sense of guilt, and a sense of ritual. Participants felt encouraged by the streamer, which increased their intrinsic motivation to study. They also felt guilty when they found the live streamers focused on finishing their plans when feeling distracted. Joining SWM was like a ritual to begin studying, helping them concentrate on finishing their daily plans. Participants viewed the streamers as their study partners and paid attention to what they were studying. Lo-Fi music helped them feel relaxed and focused, while acceptance of pure environmental sounds varied by personal preference and prior study habits. The clock component was positively reacted to by participants, making it easier for them to assess their time management and conceptualize their study efforts.

Consider Pair Programming, where two programmers work alongside on a code where one acts as the code driver and the other acts as the navigator who reviews the code, and they keep swapping their roles as they are working [4]. For some individuals, this can be a source of gaining knowledge and improving the quality of developed code. A study by Williams and Kessler [59] found that pair programming led to a 40 percent improvement in code quality compared to individuals working alone. Working in pairs can also promote better communication and collaboration, as developers must explain their thought processes and work together to find solutions.

While pair programming can provide numerous benefits, there are also potential limitations to consider. For example, if one partner is more experienced or dominant, it can lead to feelings of frustration or dis-empowerment. Additionally, if partners have different working styles or personalities, it can lead to interpersonal conflicts that can undermine the effectiveness of the partnership.

A study by Tsai et al. [56] comparing traditional and distributed pair programming in StarLogo TNG found that learners prefer traditional pair programming over individual learning. Pair programming can reduce cognitive load, improve program quality, and increase confidence. However, there is no significant difference between single and distributed pair programming. The study suggests that learning support and knowledge-sharing tools for distributed pair programming could be improved.

Job shadowing is similar to a case where an employee observes and learns from another employee who acts like a mentor. This is a very common mechanism used by companies for training interns or new employees. Depending on the amount of time spent in job shadowing, the person can learn many things essential for that job role.

In a more general and broader way, we can infer that tutoring is also something similar to body doubling, as it helps the student study and gives them a push to work on their academic submissions. We can even focus on special cases of teaching, such as sports coaching or driving lessons, where the instructor guides and corrects the person when learning and helps them to achieve their goal of learning to play or drive, respectively. In all these scenarios, we observe that some form of body doubling improves the productivity of the person doing that particular task.

One strategy for overcoming the challenges of staying active is to find an activity buddy - a friend, family member, or colleague with whom to engage in daily physical activity. Engaging in physical activity during the workday can increase energy levels, improve focus and productivity, and reduce stress and fatigue [44]. An activity buddy can enhance these benefits by providing social support, motivation, and accountability to adhere to a regular exercise routine. A study by Marcus et al. [35] found that individuals who had an activity buddy for daily exercise reported higher levels of motivation, enjoyment, and perceived social support than those who exercised alone.

In addition to providing benefits to physical health and well-being, engaging in physical activity with a work buddy can also improve workplace relationships and teamwork. Working together towards a common goal can foster a sense of camaraderie and collaboration, leading to a more positive work environment. The Virtual Fitness Buddy (VFB) [3] is an MR system designed to help children form healthy physical activity habits. The system allows children to interact with a virtual pet agent, who becomes slimmer and faster. The system rewards children for engaging in different types of physical activity and uses a “level up” system. The

VFB app encourages physical activity through social interactions with peers and parents, aligning with social cognitive theory and self-determination theory.

A study buddy is a peer who shares academic goals and works with an individual to achieve them. A study buddy can provide numerous benefits, including improved academic performance, increased motivation, and enhanced learning [2]. It also helps to provide encouragement, reduce anxiety and stress, and help individuals develop better study habits and time management skills. A study by Pintrich [42] found that students who worked with a study buddy performed better on exams than those who studied alone.

An accountability partner [20] is a person who helps individuals stay on track and hold each other accountable to their goals. They should understand the individuals' daily struggles and work through them. To find an accountability partner, the individual needs to define their expectations and boundaries and give them permission to challenge them. Sharing ownership of goal setting is personal and can be challenging, but it is essential to keep it real and motivated. To build a trusting relationship, agree on the confidential nature of your interactions and establish a time frame for regular meetings. Brainstorming and creativity together can help solve problems more easily and quickly. It is important to stay positive and receive active encouragement from the accountability partner. An accountability partner can make a difference in your life and your business by design, making a mutually beneficial, win-win scenario.

As part of this comparative study, productivity could be measured by taking ideas from Kim et al. [27], who explored how knowledge workers conceptualize personal productivity and define productive tasks in both work and non-work contexts. Six themes were revealed: work product, time management, worker's state, attitude toward work, impact & benefit, and compound tasks. The study found that participants considered the output of their activities as an important aspect contributing to their productivity. Factors influencing productivity include efficiency, intensity, punctuality, use of spare time, personal states, attitude towards work, and compound tasks. The study suggests that productivity should be treated as a multifaceted concept, and productivity tools should be designed to capture the complexity of people's perceptions of productivity.

According to Murić et al. [39], a team is a group of individuals working together to achieve common goals. There are two types of teams: structured and unstructured. Structured teams have defined roles, communication patterns, and management hierarchy, while unstructured teams lack these. Collaboration groups, or groups of collaborators, differ from traditional teams in several ways. A study analyzing GitHub and Wikipedia found that the relationship between the number of collaborators and productivity is complex and nonlinear. The marginal benefit from each additional collaborator is super-linear, but this benefit declines as the group grows. The productivity of a group as a whole is the result of increased productivity of all individual members, not just the presence of a few super-performing individuals. The relationship between group size and individual productivity is positive across all observed group sizes but becomes less prominent as groups become larger.

2.3.1 What is coworking?

Knowledge workers who are flexible and independent share open-plan offices in coworking facilities. However, coworking is typically defined as more than just having access to space and amenities; in fact, it is the elusive quality of this "working alone together" behavior that is attracting participants, attracting commentators' attention, and piquing academics' curiosity [50].

Coworking spaces have been gaining popularity for several years as a flexible and collaborative alternative to traditional office spaces. With the advancements in XR technologies, coworking spaces have evolved beyond physical boundaries, offering a virtual experience for remote workers.

XR technologies have the potential to transform the traditional coworking space model into a virtual environment that can be accessed from anywhere, anytime. This new concept of coworking spaces offers a range of benefits, including increased flexibility, reduced costs, and improved work-life balance. In terms of productivity, several studies have reported positive outcomes for remote workers using XR coworking spaces.

Social interaction is another crucial aspect of coworking spaces, and XRtechnologies offer innovative ways to foster social connections among remote workers [53]. Coworking spaces provide a sense of community and belongingness, promoting social interactions and reducing social isolation among remote workers.

Lapsomboonkamol et al. [28] explore the motivational factors affecting knowledge-sharing behaviors in co-working spaces in Thailand, using in-depth interviews. The results identify intrinsic motivational factors such as interests, altruism, and job autonomy and motivational factors such as career opportunities, networking, and rewards through knowledge-sharing behaviors in co-working spaces. Co-working spaces are often rented by freelancers and provide resources, infrastructure, and facilities to support users. Interests and career opportunities are the most significant motivators, with altruism and job autonomy being less influential. Extrinsic motivation, such as career opportunities, networking, and rewards, also motivates users to share knowledge.

The growth of co-working and co-living places has enabled digital nomads (DNs) to live location-independent lives. According to Lee et al. DNs' perceptions of co-spaces through online discussions on "/r/digitalnomad," concentrating on distant work patterns, dwelling space identification, and social infrastructure demands. The study discovered that DNs evaluate locales based on whether they allow for clear separation or integration of their personal and professional lives. DNs who choose the first type of place prioritize work productivity, while those who prefer the second type prioritize work-life balance (Figure 2.2).

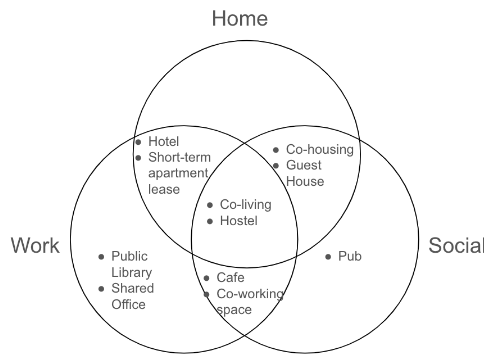


Figure 2.2: Digital nomads' perception on the places [29].

DNs often seek places to live and work, often focusing on internet availability, climate, cost of living, community, culture, language, accessibility, timezone, and safety. They often seek work and social spaces separate from their living accommodations, such as public libraries, cafés, shared offices, and co-working spaces. However, some DNs find the socializing focus of cafés distracting and prefer to work alone. DNs value their work productivity and avoid distractions, preferring their living places as work environments. Co-working spaces offer a sense of security and a good work environment

2.3.2 What is collaboration?

The concept of collaborative XR spaces has been emerging since the 1990s, with a great rise in the works being published since 2012. Although there were a few works done in this area previously, they were not able to reach widely because of the lack of technology and hardware availability. With the increase in hardware availability and the growth of technology, the focus has turned more to the area of building XR spaces.

The researchers have found the advantages and new gateways XR provides for collaborative work. "Groupware" [13] is a system that supports collaborative spaces and has divided the groupware tools into a 2x2 time-space matrix, which classifies them based on when(synchronous or asynchronous) and where(co-located or remote) individuals work together. Major work was published in remote and synchronous tasks, where individuals of different roles worked together. Collaborative spaces in XR have emerged as a new paradigm in how individuals interact with each other and their environment. Collaborative XR spaces enable users to connect and interact with each other in real-time and share information and resources, regardless of their physical location.

Collaborative XR spaces have the potential to offer several benefits to users, including increased collaboration, communication, and productivity. In a collaborative XR environment, users can work together in a shared virtual space, which can enhance their sense of presence and engagement. Collaborative XR spaces can also enable users to share data and resources in real-time, which can increase efficiency and productivity. Additionally, collaborative XR spaces can be used to facilitate remote learning, training, and communication, which can be particularly useful in contexts where physical presence is not possible or feasible.

Kantonen et al. [25] describe a teleconferencing application that uses MR. This application is built upon the Second Life (SL) [6] platform and utilizes the OpenSim virtual world. The program employs Augmented Reality (AR) methodologies to exhibit virtual representations of distant participants within actual physical environments, while Augmented Virtuality (AV) facilitates the collection of human expressions to control avatars and manipulate virtual things. The program is developed utilizing open-source technologies such as the Second Life viewer, ARToolKit, and OpenCV. The report emphasizes the growing demand for efficient teleconferencing systems as a result of economic and environmental factors. The Augmented Collaboration in Mixed Environments (ACME) technology integrates immersive virtual environments, collaborative AR, and human gesture detection to facilitate communication between the physical and digital worlds. he device is specifically built for limited conference room settings and is presently undergoing internal testing.

The Theory of Immersive Collaborative Learning (TICOL) [34] suggests that there is a need for increased distributed collaboration in a globalized world. The COVID-19 pandemic has accelerated the development of XR social applications, causing individuals to use devices to engage in virtual worlds. XR technologies differ in their sensory fidelity and support sensorimotor contingencies. XR systems using head-mounted displays provide a vivid, multi-sensory experience through visual, auditory, kinesthetic, and tactile displays. The Theory of Immersive Collaborative Learning (TICOL) is a framework that focuses on the influence of pedagogical techniques on social interaction in online collaborative learning (XRCL). Studies have found that perceived presence and co-presence in a collaborative setting are higher in XRCL than in computer-based collaborations. However, the affordances of social VR make it a particularly well-suited medium for facilitating beneficial interactions among users.

Collaboration through XR is fundamentally different from collaboration through computers due to four key psychological factors: social presence, physical presence, body ownership, and agency. These factors are experienced more strongly in XR compared to less immersive media.

2.4 RQ1: Is Body Doubling really helpful?

Body doubling is a technique used to enhance productivity where the users have another individual work beside them while they tackle a task that they may find difficult. The presence of a close individual can enhance the user's ability to concentrate, remain actively involved, and maintain the drive to complete a task. Body doubling operates under the same idea as quiet study groups, strolling companions, and public workspaces: the presence of others can alleviate the difficulty of a challenging endeavor [51]. It might be as uncomplicated as requesting the presence of a buddy to provide companionship throughout your job or as impactful as having someone physically at your side. The practice of body doubling has gained significant popularity in recent years, to the extent that it is now feasible to locate a body duplicate through online platforms. Certain web platforms necessitate payment or a subscription, but TikTok [54] serves as an additional well-liked outlet for aspiring body doubles. Body doubling can be beneficial in enhancing and maintaining motivation, particularly for individuals with ADHD who may experience diminished motivation due to neurobiological disparities.

Body doubling is an effective strategy that aids individuals with ADHD and other forms of neurodivergence in regulating their emotions and maintaining concentration during work. It entails employing a surrogate who offers a different viewpoint or serves as a source of tranquility, aiding in maintaining focus. Nevertheless, the practice of body doubling may not yield desirable outcomes in all circumstances and could potentially lead to distractions or convey bad messages. An ideal setting is characterized by its safety, supportiveness, and positive stimulation. Studies have demonstrated that social interactions stimulate the dopamine system, a crucial component of motivation and reward. Interacting with a surrogate body may enhance the production of dopamine and facilitate the identification of obstacles individuals are encountering. Additional therapeutic options for ADHD encompass the utilization of checklists, applications, cognitive flexibility, structured daily schedules, and exposure to natural environments.

The term “body double” was first coined in 1996 by Linda Anderson [1], following her experience with an ADHD client. Having individuals in close proximity fosters a sense of responsibility that draws one’s attention toward the current activity and away from distracting ideas. Anderson and Lawrenz Anderson and Lawrenz specialize in working with ADHD adults and uses organizational tools to help them achieve their goals. One such tool is the body double principle, which involves having someone nearby to help with tasks. This has been applied to clients, proving that just being in proximity can bring clarity and focus.

A body double can serve as a physical and emotional anchor for individuals with ADHD, providing a boundary and a stopwatch for their brain. It can also act as a mirror, reflecting the individual's over-stimulated mind and body. Eastern cultures examples, such as chi, use chi balancers and meditation to manage energy in their living and working spaces. A body double can be a quiet companion, providing support and guidance when needed. It's a useful tool in managing stress and staying on track, whether it's for personal use or office support.

The body double can demonstrate more efficient methods for accomplishing typical chores. Working with a body double can make tedious tasks less frustrating, creating an incentive to complete them. Engaging a body duplicate can alleviate the sense of isolation experienced by those with ADHD. The use of a body double can enhance accountability and potentially provide valuable insights on habits that may be distracting or counterproductive.

ADHD body doubling may not be effective for all individuals. The presence of a body double has the potential to divert attention and hinder focus [57]. The presence of a body double might potentially cause delays in work completion by diverting the attention of the individual. Other alternatives could be working in collaborative groups or setting personal reminders.

A body double can be someone who has the ability to maintain silence and exhibit self-reliance. Individuals have the option to engage in activities such as sitting, reading, knitting, or quietly working on a laptop. Their role is to refrain from interacting with the individual working. The body double can be hired outside, like a professional organizer or office assistant. An ADHD coach can also help identify the best strategies for an individual [1].

Academic procrastination is a prevalent issue among students, with prevalence rates double or triple those of the working population [52]. Factors like freedom, long deadlines, and distractions contribute to procrastination, negatively impacting academic performance, retention, health, and well-being. To reduce procrastination, measures like reducing unnecessary options, implementing structural arrangements, addressing task aversiveness, and limiting leisure-related internet use can be implemented. Interventions like self-determination theory, distraction reduction, and self-monitoring can help. Self-efficacy is crucial for academic performance but is often overlooked in course instruction. Peers, social norms, and distractions also play a role. The study identifies nine factors that can instigate and sustain academic procrastination, including self-regulation, skills and motivation, and social factors. These factors include self-regulation, skills and motivation, and social factors. To address these issues, it is important to design group work that encourages collaborative work and increases student accountability. Body doubling could be one such strategy that is useful to motivate and regulate.

Co-working spaces have grown everywhere. Swezey and Vertesi swezey2019working explore the challenges of working alone and apart, yet together, based on observational study and interviews at three large WeWork co-working spaces in New York City. Co-working, teleworking, and virtual teams are increasingly popular as workers move away from traditional workplaces. Computer Supported Cooperative Work (CSCW) scholars aim to address the challenges this presents by offering design concepts and analytical techniques to enable shared workspace environments and cultural codes. Co-working spaces aim to create flexible spaces for members to interact and collaborate while also fostering a sense of community among co-workers. Many individuals in the co-working space may not work on related tasks or even for the same company at all.

Flexible work may lead to work intensification and feelings of isolation. Co-working surfaces the everyday work practices with digital and physical materials that individuals deploy to be independent workers and maintain a sense of ownership over production and schedule. Communication technologies like email, Slack, Google Drive, and video conferencing software are frequently used for virtual communication and collaboration. The socio-material lens helps understand how individuals use these materials flexibly and interpretively to get their work done, manage remote work with colleagues, and maintain workplace-like relationships and friendships.

The study analyzed data from WeWork, a co-working space that began in the early 2010s and has since expanded to over a hundred cities with over four hundred locations. WeWork offers a flexible, interactionally-oriented workspace that fosters a sense of community and creativity among co-workers. The flexible material elements in the workspace contribute to a home-like atmosphere, fostering a sense of belonging and comfort. While WeWork does not benefit contractually from the interactions it promotes, co-workers continue to pay membership fees due to their connection to its intentionally crafted "community." Members are attracted to co-working not because they work productively alone but because they find working in a larger community valuable for its sense of belonging and stimulating environment.

2.5 RQ2: What does body doubling mean in MR? How is it different or similar to body doubling in the real world?

Body doubling refers to carrying out an action when another person is present. Body doubling is the practice of working on and finishing potentially difficult tasks with another person. The “body double” is this additional individual. In order to lower the risk of distraction, the body double’s role is to assist in anchoring the user to the current situation and task. The present scenario of body doubling is through the real world in a person’s body double, or through a video call. Some applications help users find a real-world body double or use video calling platforms such as Skype or Zoom to make this possible.

Many online applications that facilitate Body Doubling connect users over a video-call platform. They put together all the people who want to use body doubling and they usually monitor these sessions. One such example is FLOWN [41], which guides members in the virtual coworking session, called Flocks, on how to define practicable short-term goals for each session. Together with designed play practices and social cues, members can more easily dampen the mental ‘noise’ that can interfere with focus. According to their findings from the American Association for Talent Development, the probability of completing a goal increased to 65% when the intention to achieve it was shared with someone and further to 95% when done as part of an accountability appointment. The members of the application work in silence for 50–52 minutes, followed by a break activity.

Another example is Flow Club [46], where the Pomodoro Technique [8] is used to help users work in small time increments of 25 minutes, followed by a 5-minute break. Their most popular length of session is 50 minutes. This might be similar to working solo but with an added layer of structure and external accountability to help push ourselves a little harder.

MR is a popular user interface paradigm that enhances a user’s view by integrating computer-generated information into a real-world environment. Wang an Dunston [58] introduce two MR settings that enable individuals to collaboratively utilize a shared workspace and communication platform, both in physical proximity and from faraway locations. Two studies were conducted to evaluate the performance of the two MR systems in real-world settings and collaborative work compared to existing approaches. The results demonstrated that both MR systems substantially decreased the time required to complete the collaborative design error detection job. Additionally, the MR systems were shown to require less mental effort, indicating that a portion of the cognitive processing for the error detection task was transferred to the MR systems.

Body doubling in the real world could be distracting, based on the participants. If the participants know each other or if they are friends, they might end up talking or doing some other activity instead of working on their task. At the same time, working with an unknown person might not be comfortable for a few people, and it could also be intimidating for a few. They might not be able to focus on their work. The problem of working with an unknown could be overcome through video calls. But body-doubling over video calls may not exactly feel very realistic. When working on a computer or laptop, the user might need an extra screen to view the body double who is in the video call.

The idea behind body doubling in an immersive world could be thought of as a blend of coworking and collaborative spaces in XR, but leaning more towards coworking spaces. Body doubling in an immersive world can be implemented using MR. This way the user will be able to work on their task, as well as be able to look at their body double, who is also working remotely. It would be the same as in real-world or a video call, there would be a body double who would work on their own task alongside the user. Unlike collaborative spaces where there are many individuals who are working on the same task, and who can interact and discuss amongst themselves, body doubling involves very minimal interaction between the two participants, apart from the beginning or end of their working session. This may seem more like coworking, where individuals are working in a shared space. But the main difference between body doubling and coworking is that in body doubling, the feature which motivates the user to work is a body double who is also working. In coworking, the focus is more on creating a good space that would help the users work.

2.6 RQ3: What are the challenges in the real world, and how can they be improved in MR?

One main challenge in the real world is availability in the same location. The two individuals who are participating in body-doubling need to be in the same location to work together.

Shared-space technologies can be classified using three means: transportation, artificiality, and spatiality. Transportation measures the extent to which participants leave their local space and enter a remote space, artificiality concerns the extent to which a space is either synthetic or is based on the physical world and spatiality concerns their level of support for fundamental physical spatial properties such as containment, topology, distance, orientation, and movement [5]. The classification of shared-space approaches according to transportation and artificiality can be divided into four major strands: physical reality, VR, telepresence, and AR. Physical reality combines both local and physical aspects, while VR combines remote and synthetic aspects. Telepresence combines both remote and physical aspects, while augmented reality overlays synthetic information on the local environment. Telephone conferencing, video-conferencing, and aAR systems are all based on physical reality, while AR systems supplement the user's immediate physical surroundings with additional synthetic information. MR, which span these dimensions, integrate the local and remote aspects of shared space. The choice of display technology affects artificiality and transportation, and the medium affects artificiality.

The nature of interface technology significantly impacts transportation, with shared projected interfaces providing a high level of immersion. However, these displays may be less transporting than head-mounted displays, as they allow multiple physically co-located participants to share a single display. Desktop VR interfaces expose users to greater interference from local stimuli and distractions, causing confusion. Video-conferencing systems that use larger displays introduce a shared spatial frame of reference but only limited movement within this frame. 3D collaborative virtual environments support general movement within a shared spatial frame, allowing participants to explore a spatial environment independently while being aware of others' viewpoints through avatars.

Increasing spatiality in shared-space systems is necessary to establish reciprocity of perspective at a finer level of detail. The concept of MR boundaries could help create new forms of MR by merging real and virtual worlds within a single display technology.

Video-based teleconference systems offer a limited "tangible" multi-party meeting experience, with flat 2D upper body images and inconsistent gaze direction. VR and AR can improve this experience by creating a sense of co-presence and sharing virtual space [23]. AR-based methods have been found to have positive effects on persuasion. However, communication effectiveness depends on the qualities of the represented user and background.

The Theory of Immersive Collaborative Learning (TICOL) [34] suggests that collaboration through XR is fundamentally different from collaboration through computers due to four key psychological factors: social presence, physical presence, body ownership, and agency. These factors are experienced more strongly in XR compared to less immersive media. The sense of embodiment and body ownership in VR allows users to experience the world from other people's perspectives [18], making VR an "empathy machine."

Mahmood et al. [33] present a remote collaborative visualization system that improves information sharing and analysis experiences compared to traditional desktop visualizations. The system uses MR) techniques to enhance co-presence, information sharing, and collaborative analysis functions, allowing users to perform various immersive and collaborative analytics tasks effectively. The system consists of a server and multiple HoloLens devices connected through a wireless network, allowing users to perform various analysis tasks. The system supports multi-modal interactions, including voice, gaze, and hand gestures, and allows users to interact with virtual elements as if they were actual objects in the physical space. The system also allows users to revisit important interactions in the physical space, enhancing collaborative sense-making. The system's effectiveness is confirmed through user studies and demonstrates the potential of MR in improving remote collaboration on visualization tasks.

Another example includes a study [40] which explores the use of VR in collaborative tasks, specifically card sorting. Participants were introduced to the process through a video tutorial, which required them to share and update their team member's knowledge. The presence of avatars in the virtual environment helped participants stay aware of their team members' progress and the tasks' progress. Participants generally liked the immersive VR system for basic tasks and felt more efficient using it. They preferred the VR system for its ease of delegating tasks, seeing body language, and the feeling of being in the same room. The study concluded that the VR system was at least as good as the in-person standard for card sorting, and participants were aware of the task, team members, and context.

2.7 RQ4: What are the challenges of implementing body doubling in MR?

Optimal outcomes can be achieved by employing avatars that accurately represent human behavior and incorporating genuine local background settings. The presence and communication effectiveness of virtual humans is affected by the type of avatar and background representation. In their study, Jo et al. [23] conducted a preliminary investigation comparing 3D collaborative media in MR. They examined two dimensions: the form of the background (real or virtual) and the form of the user (photo-realistically reconstructed or pre-built 3D avatar). The study examines the differences between typical video-based systems, where both the background and the user are depicted in a genuine but two-dimensional flat screen.

In order to equalize co-presence and affect, it is necessary to add physicality, self-body representation, basic gaze behavior, and minimally realistic reconstructed avatars. The most common method for assessing co-presence in teleconferences is surveys and questionnaires. The Witmer and Singer presence questionnaire [61] was used to measure presence in virtual environments.

CoVAR [43] is a mixed-platform remote collaborative AR and VR system that combines AR and VR technologies for remote collaboration. The system supports collaboration between AR and VR users by sharing a 3D reconstruction of the AR user's environment. To enhance this collaboration, it provides natural inputs such as eye gaze and hand gestures, remote embodiment through the avatar's head and hands, and awareness cues of field-of-view and gaze cues. The system architecture focuses on sharing a 3D reconstruction of a room-scale real-world space, allowing AR and VR users to experience a shared space and collaborate on real-world tasks. CoVAR is a multi-user system with a server-client architecture, allowing different use case scenarios. The system uses the Pupil Labs system for eye tracking and the Leap Motion system for hand pose recognition.

According to TICOL [34] features that influence the four fundamental psychological factors of XRCL include depth cues, audio quality, haptic feedback, and interactivity. Immersion has been linked to higher physical presence, with increased levels of user tracking, stereoscopic visuals, and wider fields of view of visual displays being the most important technological features influencing physical presence. Physical proximity, identity cues, and the presence of virtual humans can also predict social presence.

There is an impact of video/audio communication, input device representations, and disturbance factors typical of projection-based virtual environments on co-presence, co-working, and co-knowledge in distributed collaborative virtual environments (CVEs) [17]. Remote partner representation is crucial for resolving problems, and the quality of video connection can be traded off against other representation components. Input device representations are adequate means for supporting the perception of co-presence, which is the basic requirement for collaboration. High system responsiveness is perceived as having a positive impact on collaboration. The absence of representation forms has a negative impact on usability, with missing remote partner representation handicapping the CVE team more than missing remote tool and input device representations

Traditional video conferencing technologies have limitations, such as not conveying spatial cues or sharing task space [32]. MR technology can overcome these limitations and create new types of collaborative experiences. MR environments present real and virtual world objects together, encompassing AR, AV, and VR.

Mahmood et al. [33] present a remote collaborative visualization system that improves information sharing and analysis experiences compared to traditional desktop visualizations. The system uses MR techniques to enhance co-presence, information sharing, and collaborative analysis functions, allowing users to perform various immersive and collaborative analytics tasks effectively. The system consists of a server and multiple HoloLens devices connected through a wireless network, allowing users to perform various analysis tasks. The system supports multi-modal interactions, including voice, gaze, and hand gestures, and allows users to interact with virtual elements as if they were actual objects in the physical space. The system also allows users to revisit important interactions in the physical space, enhancing collaborative sensemaking. The system's effectiveness is confirmed through user studies and demonstrates the potential of MR in improving remote collaboration on visualization tasks.

A study by Dubosc et a. [11] examining the impact of facial anthropomorphism on avatar attractiveness, social presence, and performance in collaborative tasks found no significant difference in body ownership or social presence between avatars with different facial properties. However, there were significant differences in attractiveness and completion duration of the collaborative task. The more attractive the avatar, the shorter the game completion duration. The sense of social presence appears to be task-sensitive, especially when non-verbal communication becomes more important during face-to-face interaction in immersive virtual environments. The study suggests that a more anthropomorphic appearance could favor communication in virtual environments, leading to increased performance in collaborative tasks.

Chapter 3

Design

3.1 User Study Design

Through the user study, we aim to understand if body doubling is really helpful to the users and also understand if the design of Body doubling with an MR avatar is effective. We want to get insights into whether a virtual avatar and the whole setup of using a Hololens is useful or distractive for the users. To do this, we planned to compare the participants' performance and attention in four different scenarios: when there is no body double, when there is a real-life body double, when the body double is over a video call on a tablet, and when there is a virtual body double avatar in the Hololens.

This way, we can get insights into whether body doubling is effective and useful for the general population. If it is useful, we will know which mode of body doubles the participants' favor. It also helps to understand if the virtual avatar is serving the purpose of body doubling and get suggestions on the potential improvements that can be made to make the MR setup more valuable and comfortable for the users to use.

To get better information about the participant's attention in the task we needed to use a dull and monotonous task for the study. This way the participant might be bored and distracted or might want to take a break between the short task duration.

Initially, we had to decide the means of the task on a general paper-based or a screen-based device setting. However, after doing a pilot study with both modes, we found that a screen-based task would be better, as the current generation does most of their work on a laptop or tablet. They felt a laptop or tablet is more of their space for working than a pen and paper.

We then brainstormed about different tasks that could be uninteresting or something the users might lose focus on while working on it for long hours. We devised ideas such as reading, typing, and mandala artwork. We also wanted a task that could be done in a short period of the study and give us as many metrics to measure as possible.

At the end, we settled on a task where the participant was given a set of papers with the content they would be asked to type in the laptop. During these tasks, as planned, there were four modes: no body double, when there is a real-life body double, when the body double is over a video call on a tablet, and when there is a virtual body double avatar in the Hololens. For the first three modes, no body double, in-person body double, and video-call based body-double, a Tobii Pro Glasses 2 [55] was used to collect the gaze data. In the MR mode, Microsoft Hololens 2 [36] was used to collect the gaze Data.

The autocomplete, grammar, and spelling checks in the Microsoft Word document were removed to make the task a little frustrating. For the video-call mode, a tablet was used to show the body double. In the first 3 cases, the body double was the Investigator, and in the MR mode, it was a virtual avatar. During the task, the body double also keeps working on a system, similar to the task.

As part of the task, the participants were given an article named “We’re Distracted. That’s Nothing New.” by Caleb Smith [48]. It had 3,145 words, and the article was given to the participants as a print of eight pages.

3.2 IRB Procedure

An HRP-503 Template was used for the IRB. The Virginia Tech IRB protocol number is #23-144 (Figure 3.1).

Study Title	Comparative Study of Body Doubling in Extended Reality
Study Design	A one-time 60 mins study is conducted where the participant in assigned to one of the 4 groups sequentially (in the order of without a body double, with in-person body double, with a body double over video call and body double avatar in mixed reality) and asked to perform a task. Post study participants are asked to fill an online survey which is quantitatively analyzed.
Primary Objective	The purpose of this study is to analyze the experience of body doubling in mixed reality and comparing it to in-person or video-call based body doubling.
Secondary Objective(s)	The secondary objective is to develop a body doubling environment in mixed reality which can be used by people to work.
Study Population	The results of this study are helpful for anyone who is looking for a partner to work along with as they find it difficult to work alone. This can also be very useful for people who find it difficult to focus and complete a task.
Sample Size	80
Research Intervention(s)/ Investigational Agent(s)	Post study survey which includes NASA TLX and SUS questionnaires with a few custom questions to understand the users focus and attention during the study.
Study Duration for Individual Participants	The participant will have to attend the study once for a 60 mins session which includes the study activity and survey post study.
Acronyms and Definitions	Body doubling- The practice of working on and finishing potentially frustrating jobs in the presence of another person, NASA TLX- NASA Task Load Index, SUS-System Usability Scale

Figure 3.1: IRB study summary.

As part of the study, every participant was given a $5 Amazon Gift Card for their time and effort in the study. Potential subjects were recruited by advertising a flyer on student list servers, and interested participants were selected for the study. The study took place on the university campus at Gilbert Place Building, 3rd floor, Distributed Virtual Environments Lab.

The recruitment flyer was sent to email list servers such as hci-students-g and gradstudents. Interested participants contacted the investigator about the study. Participants who showed interest in participating in the age group of 18-60 years, were English speaking, and did not belong to any of the vulnerable groups such as minors, pregnant women, etc., were recruited.

Although 80 participants were proposed in the IRB, the study was concluded with only 40 participants who were recruited in the span of 4 weeks.

A brief overview of the study as described in the IRB:

- **WELCOME AND INTRODUCTION (5 minutes):** The participants were welcomed and informed about the purpose of the study, the duration of the study, the setup, and what was expected of them. The participants were assigned sequentially to one of the groups in the order of no body-double, in-person body double, body-double over video call, and body-double in MR. These details were noted down beforehand once a participant accepted to take part in the study. All the devices used were cleaned and sanitized before the study.

- **CONSENT (3 minutes):** The participant was given time to read and sign the consent form if they agreed to participate in the study. They were also informed about how eye-tracking will be used during the study. The participants could withdraw at any time during the study.

- **TRAINING (5 minutes):** The participants were explained about the setup. In cases of no body-double, in-person body-double, and body-double over video call, the participants were informed about the setup and Tobii eye-tracking system being used. They were asked to perform a demo task of typing something in the system so that they could get comfortable with the setup. In the case of MR body-doubling, the participant could take an extra two minutess so that they get comfortable with the HoloLens headset. They would also be informed about the eye-tracking in the HoloLens and asked to perform the task of typing in the system.

- **STUDY (20 minutes):** The participants were asked to type some content into the system within 20 minutes. Instructions to the user were to type the content given to them and behave as they would if it were their own work. They were free to do whatever they wanted in general, but they were cautious about not checking any personal information on their devices. They were free to browse the internet on the laptop or walk around the room. Their performance was measured based on task completion and the number of errors in typing. Also, their attention to the task was measured using eye-tracking data.

- **POST-STUDY SURVEY (10 minutes):** The participants were asked to fill out the online survey after the task, to understand their mental workload, system usability, and their attention during the task.

- **END (1 minute):** At the end of the study, participants were given a $5 Amazon gift card. Participants who withdraw from the study for any reason were fully compensated for their efforts so far.

- All the devices were cleaned and sanitized regularly for the next user study.

The only data collected from the participants were their Names and email IDs, which were used in the consent form and to send the online Amazon Gift Card. None of their data was stored. The video recordings of the gaze data, their task content document, and their surveys are all de-identified while being stored.

The study involved no more than minimal risks found in everyday life. There was a small chance for the subject to experience eye strain, motion sickness, headache, dizziness, and fatigue, especially if they worked with Microsoft HoloLens [36] when assigned to the MRbody double group to perform the task. Since it is a short session, the chances of the subject experiencing any such risk were minimal. The investigators did not find any potential social, legal, privacy, or economic risks.

3.3 Data Collected

Various metrics were collected from the study. All of these were done to get a better understanding of the users' perspectives and also gather as many proofs as possible.

3.3.1 Task Content Similarity

Task Content Similarity was measured to evaluate the accuracy of the work by comparing the content typed by the user to the original article. For this purpose, Virginia Tech's iThenticate website [21] was used (Figure 3.2). The participant's document is compared against an original content document trimmed to the content typed by that participant. The doc-to-doc comparison compared the documents for spelling and punctuation differences.

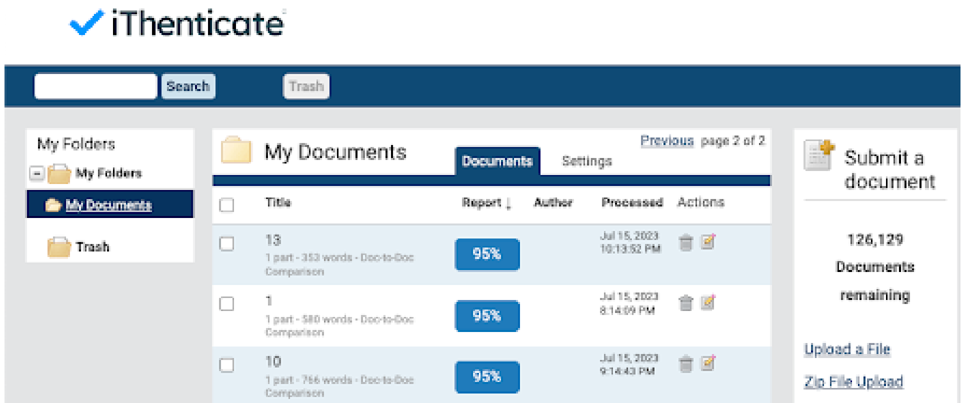


Figure 3.2: VT iThenticate.

3.3.2 Text Completion Rate

Task completion was measured as the percentage of words typed out of the total content. This is calculated to understand productivity and the level of work completion (Figure 3.3).

$$\text{Task Completion Rate} = \frac{\text{words typed}}{\text{total number of words}} \%$$

Figure 3.3: Task Completion Rate.

3.3.3 Gaze Data

Gaze data is captured and analyzed to observe how distracted the participant was during the task. Since the participants behavior can not be collected by observing them throughout the study, we used different gaze-tracking devices during the study.

The Tobii Pro glasses [55] (Figure 3.4) record a front view video and the sensors around the lens capture gaze data.

Microsoft Hololens 2 [36] (Figure 3.5) has a built-in Gaze tracking feature that records and could be used to collect gaze data using some tools.

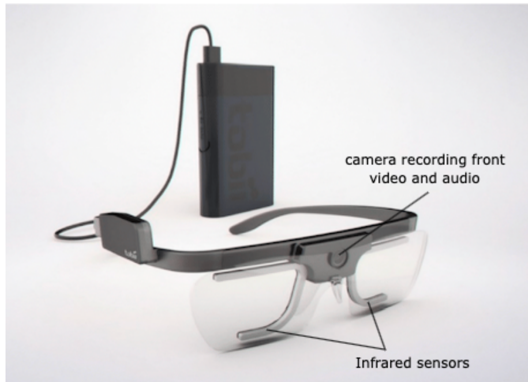


Figure 3.4: Tobii Pro Glasses 2.

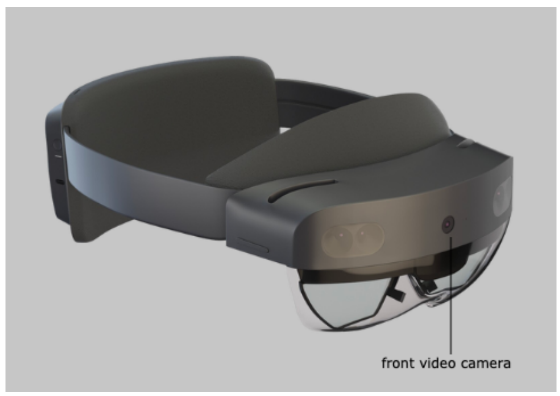


Figure 3.5: Microsoft Hololens 2.

Both the trackers had good technology to accommodate a wide range of users. People using vision-correcting glasses can still use these devices without any issue with the data being recorded.

3.3.4 Surveys

Lastly, there were surveys filled out by the participants at the end of the study that helped to get the participants' perspectives about the study. The following questionnaires were included in the study, with an additional comments section.

1. NASA TLX Survey: To understand the task load during the study.

2. SUS Survey: To understand the usability of the system.
3. Task Attention Survey: To gauge the participants' perspective of their attention during the study.
4. Comments: So that the participants can add any other insights about the study in general.

3.4 MR Design

3.4.1 Design Proposal

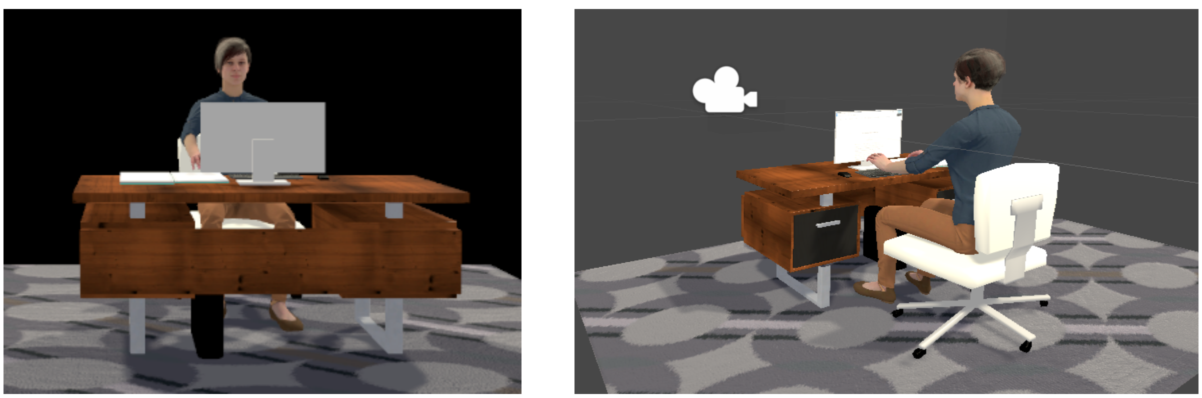
Initially, for the MR mode, the idea was to design a virtual avatar who is working. This way, the user need not coordinate and plan with someone about when and where to work. They can use the Hololens headset whenever they feel they need some presence to work on their task. For most tasks, this gives them the freedom to work whenever and whatever they want to work on. Since Hololens supports viewing real-world objects, they can efficiently work on their personal task. It may not be optimal for physical tasks such as exercising or playing outdoor games. Still, it helps with general academic or office work, which people feel bored about or need some presence around so they don't get easily distracted.

This is also inspired by the idea of "Study with me" videos on YouTube, where a person is often seen working on their academic work for a period of time. Most videos range from 3-4 hrs with regular intervals of break.

The MR headset can be tiring for long hours of tasks because of the weight of the headset and the inconvenience of putting it on for long hours, especially for individuals who use vision glasses or who are prone to getting headaches when weight is put on their head for an extended period of time. For this reason, additional features, such as a Pomodoro timer [8], can be included in future versions.

3.4.2 Designed work

For the study, a general virtual avatar from Mixamo was used (Figure 3.6). The avatar is seen to work on a computer, similar to the task the participant in the user study would perform. The avatar would be typing out some content from a notebook on the computer. No additional interactions were added to the avatar, as it could distract the user and deviate from the idea of body doubling, where, in most cases, the other person is only doing their work.



(a) Front view. (b) Side view.

Figure 3.6: MR avatar.

An animation was added to the Avatar GameObject to give action to the avatar (Figure 3.7). The Mixamo GameObject had a general Humanoid Rig for each body part, such as the head, neck, shoulder, arms, fingers, etc. When a GameObject is Humanoid Rigged, each body part can be individually identified and controlled. Using the Rig, we can control the motion of each body part. It can be done by recording the avatar's action or changing the three-dimensional Scale and Rotation Key frames of each GameObject Rig.

The avatar had no facial Rig A facial Rig for the avatar must be designed and combined with the original body Rig to add facial expressions. The avatar didn't need any mode of interaction for the concept of Body Doubling. Also, it was complicated and diverted from the original purpose of testing if the virtual character was a good alternative to a Body Double. So this part was not added to the design currently.

Figure 3.7: Animation for the avatar.

The animation for the design started with a primary position where the avatar is seen sitting at the desk. Different typing movements were recorded. They were all combined and added to the avatar. A few minute changes to the animation were done at the end by changing the Key-frame values of the Rotation and Scale of each Rig.

In order to add it to the scene, this animation was added to the Avatar GameObject. The typing animation can be made as a loop, and the rate at which it plays can also be altered in the Animator view (Figure 3.8).

A script was added to the Unity application to collect the Gaze data during the User Study.

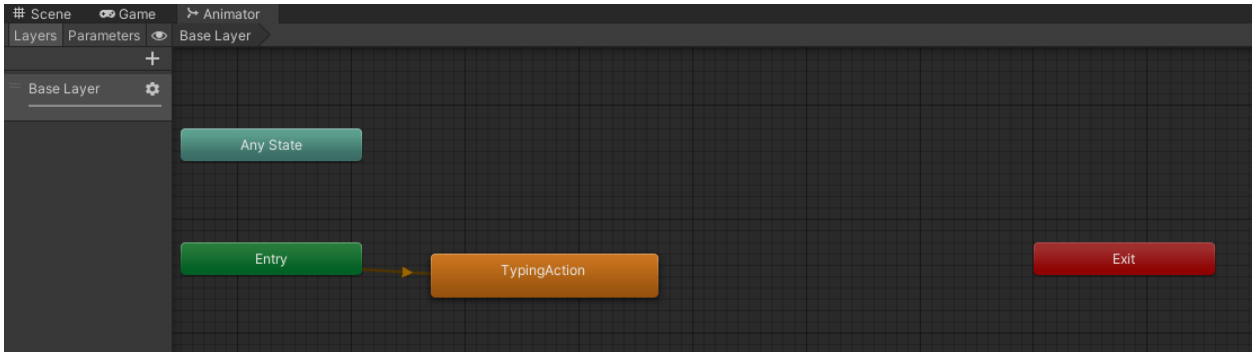


Figure 3.8: Animation for the Avatar

The Hololens has the option to Live record what the user sees. But it does not give accurate gaze data; it just shows the view of what is visible to the user at that moment. For this purpose, after setting up eye tracking in the Microsoft Mixed Reality Toolkit(MRTK) scene, we can use CoreServices.InputSystem.EyeGazeProvider [38] in a MonoBehaviour script. This provides the default gaze provider implementation registered in the toolkit at runtime, which includes properties such as GazeOrigin, GazeDirection, GazeTarget, HitPosition, etc. Using this, we can get a clear idea of where the participant is looking at during the study (Figure 3.9). All this data is stored as string data in a CSV file in the Hololens application data space whenever the application is run.

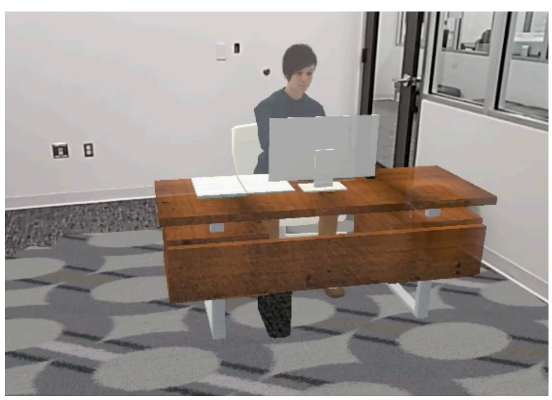


Figure 3.9: Microsoft Hololens view.

Chapter 4

Results

The primary aim of the study is to understand if Body Doubling was really helpful. In the process it also aimed to understand if MR Body Doubling is useful and what improvements can be made to the current design to make it a more effective and reliable alternative to the current modes of Body Double. The study had good results in this aspect.

All the survey results were stored and analyzed in Microsoft Excel [37]. The Data Analysis tool in Excel was used to perform ANOVA: Single Factor Analysis [45] on the results for each survey individually.

4.1 Initial Results

As part of analyzing the performance and productivity of participants in the task, their task accuracy and task completion level were calculated.

For task accuracy, the Task Content Similarity was calculated using the iThenticate Doc-to-Doc comparison tool. The results showed that the average task content similarity was 93.5%, varying between 93% and 94% among different modalities. With a p value of 0.95, it is clear to assume that the differences did not have much statistical significance. All participants have performed on a similar level.

From the average results of the task completion rate, which is measured as the percentage of words typed to the total number of words in the content, it can be seen that participants performed the best when there was an in-person body-double and completed the least amount of the task in the no body-double mode (Table 4.1). This excludes 2 special cases during the study where the participants performed differently from the rest of the study population.

Since the p value (0.085) > 0.05, this difference is statistically insignificant. Their progress could be considered almost the same. But this productivity could also be attributed to them being a part of the user study.

Table 4.1: Average Task Completion rate from the user study survey.

Mode of Body Double	Average Task Completion Rate
No Body Double	**12%**
In-Person Body Double	17%
Video-Call Body Double	14%
MR Body Double	14%

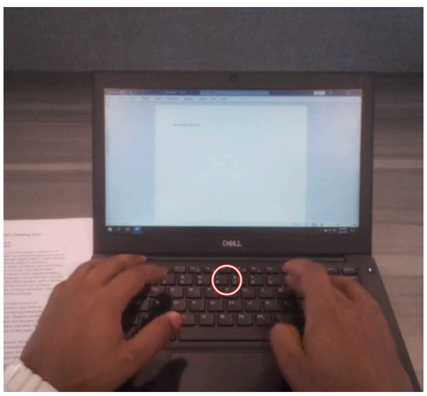
Two interesting observations during the study were:

- One participant in the no body-double mode **did not type anything during the study**. The participant just read through the content during the entire study duration and browsed through the internet about different topics, such as the article and the eye-tracking glasses. When asked about the reason behind it, they said the article was interesting, and as they were reading and searching about the topic, they wanted to learn more about how the eye-tracking device works when the user has a "lazy eye."

- Another participant was in the in-person body-double mode, where they skimmed the entire content in 6 minutes and then **typed out a summary of the article**. When asked why they summarized instead of typing the whole content, they said it was their general habit to read and write conclusive content. So when the study investigator discussed the task and told them to do it in their natural style and not forcefully do the task because it was a part of the study, they completed the task that way.

4.1.1 Gaze Data Insights

Gaze data is observed from the video recordings from the head-mounted devices used (Figure 4.1). The Tobii glasses recordings had a circular gaze pointer which shows what the participant in looking at. For the Hololens recordings, the script designed when the avatar was designed provides the gaze details.



(a) Tobii gaze tracking.

Timestamp	GazeObject	GazeDirection			GazeOrigin		
6/16/2023 1:33:53 PM	RearWall (UnityEngine.GameObject)	0.0	0.1	1.0)	0.0	0.0	0.0)
6/16/2023 1:33:54 PM	SpatialMesh - 4D2B18AECE158A38-7E30BBEBFB5F6DA2 (UnityEngine.GameObject)	0.0	0.2	1.0)	0.0	0.0	0.0)
6/16/2023 1:33:55 PM	Avatar (UnityEngine.GameObject)	-0.2	0.1	1.0)	0.0	0.0	0.0)
6/16/2023 1:33:56 PM	SpatialMesh - 4B99830BE781B738-5994A1DFF990C598 (UnityEngine.GameObject)	-0.2	0.1	1.0)	0.0	0.0	0.0)
6/16/2023 1:33:57 PM	Avatar (UnityEngine.GameObject)	-0.2	0.1	1.0)	0.0	0.0	0.0)
6/16/2023 1:33:58 PM	Avatar (UnityEngine.GameObject)	-0.1	0.1	1.0)	0.0	0.0	0.1)
6/16/2023 1:33:59 PM	Avatar (UnityEngine.GameObject)	-0.2	0.1	1.0)	0.0	0.0	0.1)
6/16/2023 1:34:00 PM	Avatar (UnityEngine.GameObject)	-0.2	0.1	1.0)	0.0	0.0	0.1)
6/16/2023 1:34:01 PM	Avatar (UnityEngine.GameObject)	-0.2	0.1	1.0)	0.0	0.0	0.0)
6/16/2023 1:34:02 PM	Avatar (UnityEngine.GameObject)	-0.2	0.1	1.0)	0.0	0.0	0.1)
6/16/2023 1:34:03 PM	Avatar (UnityEngine.GameObject)	-0.2	0.1	1.0)	0.0	0.0	0.1)
6/16/2023 1:34:04 PM	Avatar (UnityEngine.GameObject)	-0.1	0.1	1.0)	0.0	0.0	0.1)
6/16/2023 1:34:05 PM	Avatar (UnityEngine.GameObject)	-0.1	0.1	1.0)	0.0	0.0	0.1)
6/16/2023 1:34:06 PM	Avatar (UnityEngine.GameObject)	-0.2	0.1	1.0)	(-0.1	0.0	0.1)
6/16/2023 1:34:07 PM	SpatialMesh - 4D2B18AECE158A38-7E30BBEBFB5F6DA2 (UnityEngine.GameObject)	-0.7	0.3	0.7)	0.0	0.0	0.1)
6/16/2023 1:34:08 PM	Avatar (UnityEngine.GameObject)	-0.2	0.0	1.0)	0.0	0.0	0.0)
6/16/2023 1:34:09 PM	Avatar (UnityEngine.GameObject)	-0.2	0.0	1.0)	0.0	0.0	0.0)
6/16/2023 1:34:10 PM	Avatar (UnityEngine.GameObject)	-0.2	0.0	1.0)	0.0	0.0	0.0)
6/16/2023 1:34:11 PM	Avatar (UnityEngine.GameObject)	-0.2	0.0	1.0)	0.0	0.0	0.0)
6/16/2023 1:34:12 PM	Avatar (UnityEngine.GameObject)	-0.2	0.0	1.0)	0.0	0.0	0.0)
6/16/2023 1:34:13 PM	Avatar (UnityEngine.GameObject)	-0.2	0.0	1.0)	0.0	0.0	0.0)
6/16/2023 1:34:14 PM	Avatar (UnityEngine.GameObject)	-0.2	0.0	1.0)	0.0	0.0	0.0)
6/16/2023 1:34:15 PM	Avatar (UnityEngine.GameObject)	-0.2	0.0	1.0)	0.0	0.0	0.0)
6/16/2023 1:34:16 PM	Avatar (UnityEngine.GameObject)	-0.2	0.0	1.0)	0.0	0.0	0.0)

(b) MR captured gaze data.

Figure 4.1: Gaze tracking data.

- **No Body Double:** Half of the participants worked for the most part, while the other half browsed the internet. One participant put on music and read through the content after some time. One participant did not type anything during the study; they just browsed through the internet.

- **In-person Body Double:** Most of them worked throughout without many distractions. They looked a few times at the body-double in-between but worked for the majority of the study. Towards the end of the study, one person copy-pasted a part of the article online and started looking around. One participant skimmed the entire content in 5–6 minutes and then typed out a summary of the article.

- **Video-call based Body Double:** Most of them worked throughout without many distractions and looked a few times at the body double in between. Three participants were browsing the internet about the article or news towards the end of the study.

- **MR Body Double:** Most of them worked throughout without many distractions. They all observed the body double and its motions in between the tasks, and one participant even tried to walk around the virtual avatar.

The virtual avatar and its actions seemed to be interesting to most of the users in the MR mode.

4.2 NASA TLX Survey

The NASA Task Load Index (NASA TLX) is a commonly employed subjective evaluation instrument that quantifies the perceived workload and cognitive demands encountered by humans when carrying out various tasks, particularly in situations that require high levels of effort and involve intricate complexities. The National Aeronautics and Space Administration (NASA) developed it in 1988 [19] to evaluate the cognitive and physical burden of astronauts during space missions. However, it has subsequently been modified for other purposes.

The NASA TLX assessment typically comprises the following constituents:

Mental Demand: This element evaluates the degree of mental exertion, focus, and cognitive burden necessary for the task.

Physical Demand: This metric assesses the level of physical exertion and strain involved in completing the task.

Temporal Demand: This element quantifies the impact of time pressure or pacing on the effort of the task.

Performance: Participants are required to evaluate their own performance on the task.

Effort: This component pertains to the perceived exertion necessary to successfully complete the task.

Frustration: It measures the degree of frustration or discontent encountered during task execution.

The components of NASA TLX survey are rated by users on a scale of 0 to 100, where higher scores indicate a greater perceived effort. The scores from each component are aggregated to yield a comprehensive workload evaluation, which is valuable for analyzing and comparing various tasks, systems, or job responsibilities. The NASA TLX survey (Figure 4.2) has been utilized across multiple domains, such as aviation, healthcare, human factors engineering, and usability testing. Its purpose is to better system and task design by minimizing cognitive and physical workload, improving safety, and optimizing performance.

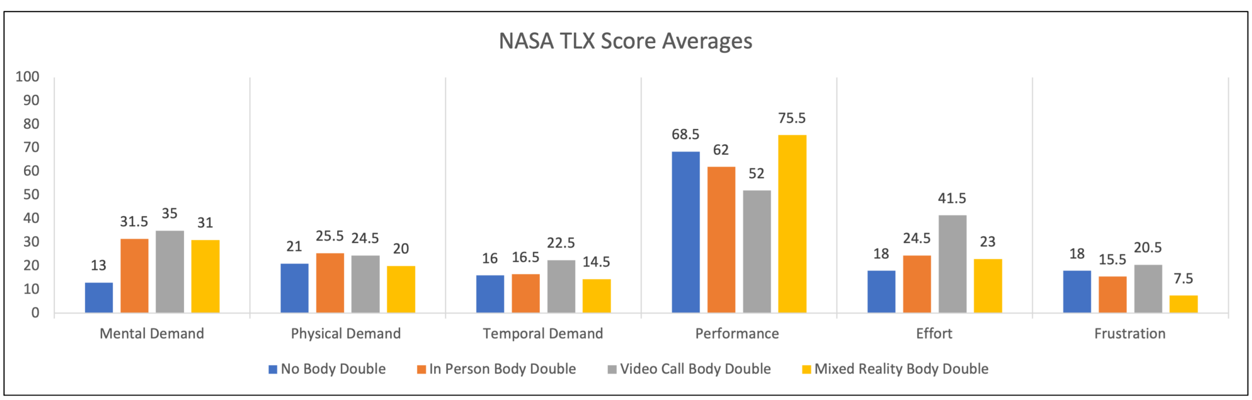


Figure 4.2: NASA TLX Survey.

In general we observe a comparatively higher average for Mental Demand, Temporal Demand and Effort for Video-call based mode, and a lower average for No body double mode

(Table 4.2). This can be attributed to the number of devices the participant is being exposed to in the video-call mode. Which, in turn, adds a lot of cognitive load to the participant.

Another interesting observation is that there is a higher Performance and lower Frustration for the MR mode, while the rest of the averages seem close to the other averages. This could be seen as a good indicator of the MR mode aiding the participants' performance.

Table 4.2: NASA TLX Survey results.

	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
No Body Double	13	21	16	68.5	18	18
In-Person Body Double	31.5	25.5	16.6	62	24.5	15.5
Video-Call Body Double	35	24.5	22.5	52	41.5	20.5
MR Body Double	31	20	14.5	75.5	23	7.5
p value	0.18	0.95	0.83	0.35	0.13	0.64
Significance	no	no	no	no	no	no

ANOVA: Single-factor analysis [45] was done to check the significance of the results. However, the p values for all 6 components were greater than 0.05, making all these differences statistically insignificant.

We can say that although the results seem a little favorable towards the MR mode, this data cannot be used as conclusive proof for it. It could mean a small proportion of the population did favor the MR mode, but it could not be the general result of the population.

However, it is interesting to note that many comments in all the modes seemed to favor the idea of a body double being a motivating factor.

4.3 SUS Survey

John Brooke established the System Usability Scale (SUS) [7] in 1986 as a concise and informal measure of usability. The scale was devised to offer a straightforward yet efficient approach to evaluating the perceived usefulness of a technology. The System Usability Scale (SUS) was designed as a tool for usability professionals who need a straightforward, efficient, and cost-efficient approach to evaluating usability (Figure 4.3). The SUS comprises 10 items, each employing a five-point Likert scale ranging from Strongly Disagree to Strongly Agree. Questions are formulated in both affirmative and negative structures to encompass a wide spectrum of user perspectives. The scoring process entails deducting 1 point from odd-numbered questions and deleting 5 points from even-numbered questions. The resultant ratings are subsequently summed up and multiplied by 2.5, converting into a numerical scale that spans from 0 to 100, offering a quantitative assessment of perceived usability.

Greater scores correlate with superior usability. The average score on the System Usability Scale is 68. The System Usability Scale (SUS) is widely regarded as a versatile instrument that can be applied to a diverse array of products and services, encompassing software, hardware, and websites. Its inherent simplicity renders it adaptable to diverse circumstances, and it may be effortlessly administered to users. The reliability and consistency of SUS have been demonstrated in various investigations and circumstances. While the SUS is not a comprehensive measure, its efficient and basic nature makes it a useful tool for practitioners looking for a straightforward usability evaluation.

Figure 4.4 shows the SUS results for the tasks performed for different modalities. The results show that all the modes have a SUS score greater than 68, denoting that they are all above the average SUS score. Furthermore, the participants ranked the in-person body-double mode as simpler and easier to use, with an SUS score of 80.25, while the MR body-double

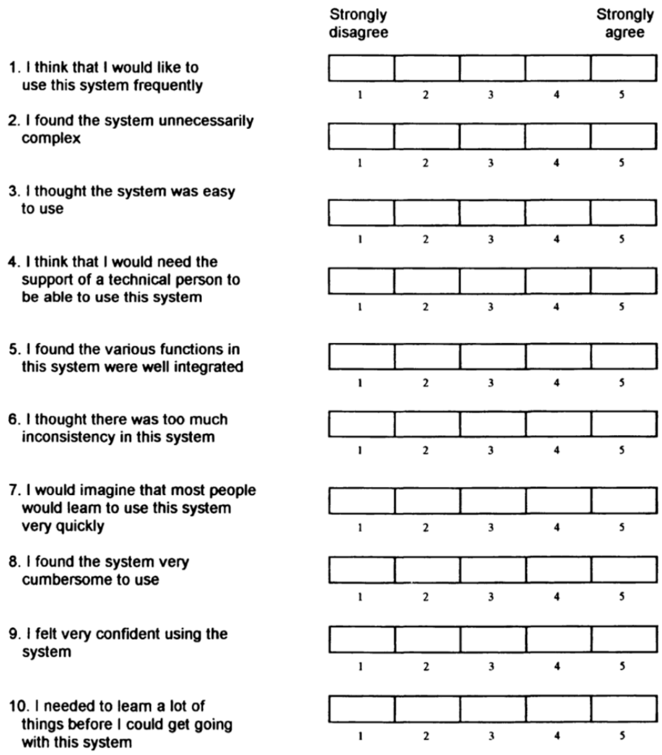


Figure 4.3: System Usability Scale [7].

mode had the lowest ranking with an SUS score of 70. The no-body-double and video-call body-double modes fell in between, with SUS scores close to the in-person mode.

The higher score in the case of In-person could be taken as a sign of a better and more realistic presence that the participant feels in this mode. It could also be linked to the simplicity and confidence that the participant got when the study investigator was in the same room. This could be supported by the fact that, unlike other modes, there were no critical comments about improvement in this mode.

The lower SUS Score for the MR body double mode has been attributed to the Hololens headset being heavy to use over a period of time, and it's narrow visibility, driving away from the idea of Body Double presence. Three out of 10 participants said that they felt the **Hololens visibility was narrow**, and most times while working, they **could not see**

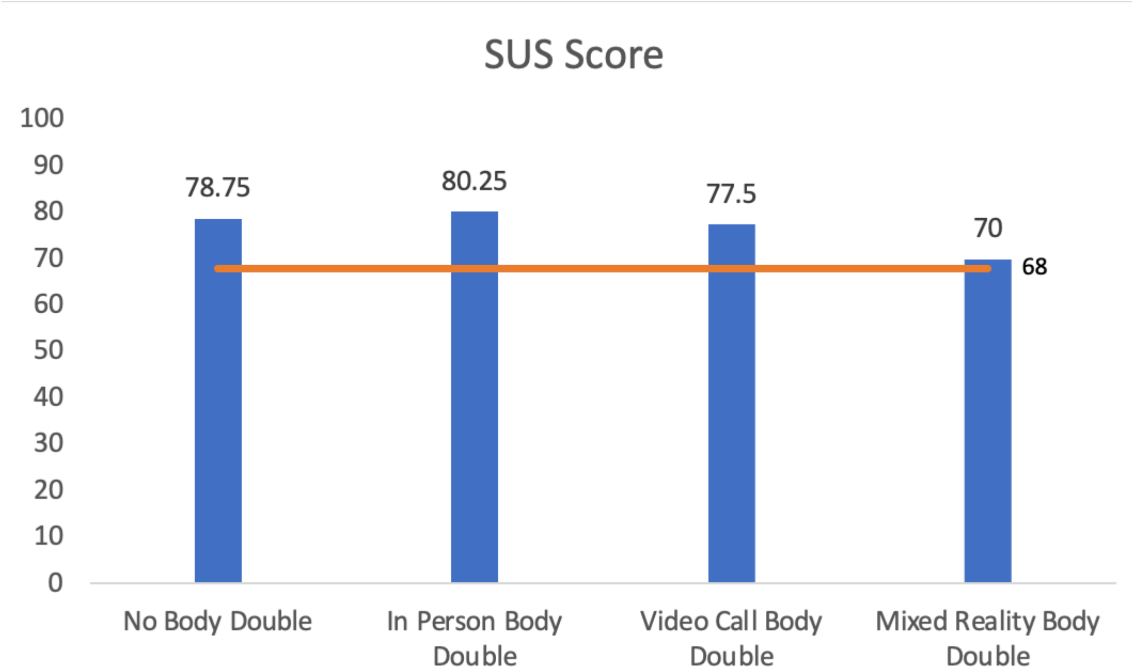


Figure 4.4: SUS Survey results.

the peripheral view of the avatar unless they tilted their head. A few of the comments shared by the participants were:

"Was excited to use the Holo lens as it made my work less boring. Although, might not be able to use it for a very long time without a break."

"The headset was bit heavy, besides that everything was fine."

"In Hololens, its displays are covering the immersive environment too narrowly. Therefore, when I look at the computer screen to type, I cannot see the character with my side vision."

For the rest of the modalities, a Tobii eye-tracking [55] device was used to track the participants' gaze. In those modes, only two participants in Video-call mode complained about the glasses, *"made me feel dizzy, felt a little uncomfortable or restricting at times"*. This could be attributed to the use of two screens, a laptop and a tablet, at the same time.

Although the participants were excited to use the MR headset, they liked the simpler and more realistic experience of in the In-person Body Double.

In order to understand the significance of these results, an ANOVA [45] test was performed on the SUS scores from the 4 modes. The p value was $(0.227) > 0.05$. So this concludes that the differences in the scores were insignificant.

Even though there seems to be a difference in the SUS Score for the MR mode, these scores might be very insignificant when we consider the overall population in general. But these results could also be attributed to the different eye-tracking devices used during the study and cannot be concluded as the scores for the different body-double modes in general.

4.4 Task Attention Survey

Although the NASA TLX and SUS Surveys tell much about the participants' opinions about the task and the different system modalities, they do not capture if the participant was attentive and motivated to do the task. For this purpose, different other metrics, such as eye-tracking, task completion level, task accuracy, and comments, were incorporated into the study. In addition, a short survey was added to understand the participants' opinions about their attention and motivation.

Different questionnaires such as SMART Survey for Memory, Attention, and Reaction Time (SMART) [10], and ADHD Questionnaires were referred to frame questions. They seemed very long and often not relevant to the idea of the study. We also had to keep the questionnaire short as the participants already participated in a 20-minute study. Other surveys such as Witmer and Singer Questionnaire for presence [61], and Igroup Presence Questionnaire [47]. However, they focused more on the virtual presence, and we planned to maintain a common questionnaire for all modes. So, we gave the option to fill out any of the participant's reviews about the study in the comments section at the end.

A custom survey consisting of the following 7 questions was included, along with NASA TLX and SUS Surveys (Figure 4.5).

	1	2	3	4	5
I was attentive throughout the task.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I understood the content I was typing during the task.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
After some duration of time, I may need some external stimuli or incentive to continue doing the task.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I found the task to be boring and monotonous.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I felt distracted few times in between the task.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I was thinking about quitting the task before it was done.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I would have done the task with the same focus, even if it was not a part of the user study.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Figure 4.5: Task Attention Survey.

1. **Q1: I was attentive throughout the task.**

Table 4.3: Task Attention Survey: Q1 results.

Mode of Body Double	Q1 Results
No Body Double	2.3
In-Person Body Double	1.9
Video-Call Body Double	1.6
MR Body Double	1.6

The averages of answers show that most of the participants believed they were attentive throughout the task (Table 4.3). There was a noticeable between the no body-double and body-double modes. A p value (0.28) $>$ 0.05 showed there were no statistical significance to these results over a large population. However, it shows that having a body-double was indeed helpful in performing the task. It helped make the participants more attentive compared to doing the task alone. This can be attributed to the feeling of a presence around them that pushed them to stay attentive throughout the task. When looking into the individual survey results, three participants in the no body-double mode chose to Disagree(4) with this statement. While the majority of the rest of the participants chose to answer between Strongly Agree(1) and Agree(2) for this statement.

2. **Q2: I understood the content I was typing during the task.**

Table 4.4: Task Attention Survey: Q2 results.

Mode of Body Double	Q2 Results
No Body Double	2
In-Person Body Double	1.8
Video-Call Body Double	1.4
MR Body Double	2.1

Looking at the results in Table 4.4, we can observe that most of the participants "Agree" that they understood the content they were typing as part of the task. The idea was to give the participants long and uninteresting content with punctuation so they would get frustrated while typing it. Most participants were surprised and overwhelmed when given a set of eight pages to type during the 20-minute duration of the task. However, it came as a surprise at the end of the study when some participants inquired about the article that was used in the task content. They wanted extra time after the study to read through the article. The p value $(0.29) > 0.05$, and no statistical significance could be observed with these results.

In the case of Video-call body double mode, we notice a significant difference, with most participants inclined towards stating that they "Strongly Agree" they understood the task content. There was no evidence in the participants' comments for why they believed this way. Based on their gaze data, the common behavior that was observed in the participants was that they had the task of typing content right below the tablet, where the study investigator was visible through a video call. This could be considered a motivating factor for them to concentrate on the task However, the close presence of the body double in the eyeline of the participants cannot be fully considered as a positive impact, as participants have commented that the motion of the body-double easily distracted them. Half of the participants in the Video-call body-double mode said they felt more inclined to work as they felt someone was monitoring them. Few of them took it as a motivating factor, while few others took it as a pressuring factor.

3. **Q3: After some duration of time, I may need some external stimuli or incentives to continue doing the task.**

Table 4.5: Task Attention Survey: Q3 results.

Mode of Body Double	Q3 Results
No Body Double	2.4
In-Person Body Double	2.5
Video-Call Body Double	2.4
MR Body Double	2.2

When asked if they would need external stimuli or incentives to work on the task over a longer duration of time, participants from all the different modes were on a similar page to "Agree" (Table 4.5). This emphasizes the need for the presence of a body-double. But a p value (0.92) > 0.05 makes these results statistically insignificant. Keeping aside the system usability issues such as the eye-tracking glasses or the MR headset, most of the participants who were part of any of the body-doubling modes commented that the presence of a body-double played a crucial part in making them work on the task after a period of time during the study.

Most participants said the feeling of someone watching them or looking at someone working was really helpful in motivating them to get back to the task and not get distracted. Few participants commented that the presence of a body double played a crucial part as it *"helped me to concentrate more on the task because I had this feeling that someone was observing"* and *"having a person next to me working has motivated me to work"*. This shows that most participants appreciated a motivating presence around them when working on something, as long as it was not distracting them from their work. It motivates them to perform better and not give into other distractions, such as using their mobile device. It helps to monitor the person's behavior, and they feel they are expected to work because they feel someone is watching them.

4. **Q4: I found the task to be boring and monotonous.**

Table 4.6: Task Attention Survey: Q4 results.

Mode of Body Double	Q4 Results
No Body Double	2.6
In-Person Body Double	2.4
Video-Call Body Double	2.5
MR Body Double	2.3

When asked if they found the task to be boring and monotonous, participants from all the different modes were of similar opinions in choosing between "Agree" or "Neutral" (Table 4.6). This helps to corroborate the idea that the study task is indeed uninteresting. The p value was (0.93), meaning there is no statistical significance. On another note, this could be attributed to the content being interesting to most participants.

Although a large majority of the participants found the task content interesting, many felt the task was very tedious. In fact, two participants in the no body-double mode explicitly commented that the *"task was boring, and I would not have done it if it were not for the study"*. Many participants in the other modes said that various factors, such as being a part of the study, using the different gaze-tracking devices, and a body double's presence, pushed them to work on the task.

5. **Q5: I felt distracted few times in between the task.**

Table 4.7: Task Attention Survey: Q5 results.

Mode of Body Double	Q5 Results
No Body Double	2.5
In-Person Body Double	2.7
Video-Call Body Double	2.4
MR Body Double	3.2

This statement was asked to understand if the participants actually felt distracted in between the task and to gauge if the body double was impacting them in any way (Table 4.7). The p value $(0.48) > 0.05$ means these differences have no statistical significance. Although the results are not that much of an indicator if they were actually distracted, they do provide insights on a few aspects to notice. In no body double and video-call body double modes, participants have explicitly commented that they felt distracted. In no body double mode, many participants felt bored and distracted in between the task. Few comments supporting this were: *"task was boring, started looking at my phone, got distracted, frustrated "*. In video-call based mode, two participants commented: *"distracted by the people in the background; presence of another person online didn't distract me, the movement of their head did"*. As observed earlier, this could be attributed to the task content sheets and the tablet being placed closely and being viewed in a closer line of sight. Any sudden movement in their peripheral view caused a distraction to the participant.

In order to justify a better score for the MR body-double mode, the participants' general gaze behavior in all modes was observed. In the first three modes, most participants seemed distracted in between and doing something else, such as looking around or browsing the internet. But in the MR mode, they were more focused and looked at the virtual avatar in between to observe its movements. This could be because of the MR device, which confines their view, or the intrigue in the virtual avatar, consequently making them more focused on the task.

6. **Q6: I was thinking about quitting the task before it was done.**

Table 4.8: Task Attention Survey: Q6 results.

Mode of Body Double	Q6 Results
No Body Double	3.1
In-Person Body Double	3.4
Video-Call Body Double	4
MR Body Double	4.4

Participants are more neutral towards the statement if they think of quitting the task before completion in no body-double mode (Table 4.8). But there is a steady inclination towards "disagreeing" with this statement when there is a body-double involved in the task. For these results we got a p value (0.103) $>$ 0.05, meaning there is no statistical significance. In the in-person body-double mode, although the results are better than in the no body-double mode, a few participants still seemed to agree a little with this statement. But in the other two modes, most participants chose between "Disagree" and "Strongly disagree," with the maximum number of participants in the MR mode strongly disagreeing with this statement. This is a great indicator of the body-double helping the participants complete a task. It also shows that the MR mode helps the participants concentrate better on the task.

7. **Q7: I would have done the task with the same focus, even if it was not a part of the user study.**

This statement was included to understand if the task being a part of the user study impacted the participants' focus on the task (Table 4.9). However, these results didn't seem to match up very well with the participants' actual behavior. Most participants

Table 4.9: Task Attention Survey: Q7 results.

Mode of Body Double	Q7 Results
No Body Double	2.5
In-Person Body Double	3.1
Video-Call Body Double	3.4
MR Body Double	2.7

chose between neutral, disagree, and strongly disagree. A small part of the participants in each mode agreed with this statement, making the average answers closer to neutral. The p value $(0.104) > 0.05$ makes these results statistically insignificant. But the better opinion in no body-double raised a few questions because most of the previous answers showed that the participants liked the other modes better. On closely observing the comments and behavior of the participants who chose to agree with this statement, it was seen that they were distracted in between the tasks, doing other activities in between. This shows the statement may have been misinterpreted as performing on the same level, which could either be good or bad, rather than at a good level. This explained a better result for the no body-double mode.

The power of all these results is estimated to be 0.37 with a medium to large effect size.

Chapter 5

Discussion

This research aimed to understand if Body doubling is helpful to the users and if the MR mode would be a good addition to the existing methods of in-person and video-call-based body doubling. In this process, we tried to observe if users were making better progress in their work and analyzed if Body Doubling is helping them stay more focused without getting easily distracted.

Overall the results may not have shown a clear statistical significance. Through the user studies and the survey results, it can be inferred that most users appreciated the presence of a body double in each of the modes. The majority of the participants felt that the body double helped them concentrate better, and some participants explicitly commented that they would not have been able to complete the task if it were not for some kind of body double presence that motivated them to keep working. However, there was a very small population that felt the no-body double mode was better than any form of body double as they felt they could concentrate better that way.

Most results seem to be aligned with what was expected from the user study, which is a body double being helpful to motivate users to work better. Most participants were intrigued with the idea of the study and were interested in participating and providing feedback to make the system better genuinely. Participants were excited to be a part of the MR body double mode, majorly because of the opportunity to try the Hololens. There were also a few participants who were interested in knowing how the Tobii Pro glasses [55] work and inquired about them.

A few of the survey results were a little more insightful about the user's expectations from the body double.

- One participant commented: *"I think the eye-tracking device maybe did more than having another person there. Like, knowing (or thinking) that my gaze and what I was looking at was going to be recorded and analyzed later made me feel like I had to be more on task."*.

- Few participants complained about the Tobii glasses making them dizzy, in video-call mode, this could be because of an added screen compared to other modes.

- Two participants in the video-call mode said they were distracted by the movements in the background of the body-double. This is attributed to the task content sheets and the tablet being placed closely and being viewed in a closer line of sight added a form of distraction when there were sudden movements in the background.

- The weight of the Hololens would make it difficult to work for longer periods of time. The Hololens visibility is narrow, and most times they could not see the virtual avatar from the peripheral contradicting the actual purpose of the study.

  We did consider the device weight issues while using hololens for the MR mode. We hoped that the Tobii eye-tracking glasses, used for gaze-tracking, would balance this effect in the rest of the methods.

- Two of them said it would be interesting to have multiple body-doubles around them. This could be thought of like a library or office setup.

  This could be considered as an added feature for the future. Currently, the research stuck to the standard idea of having only one Body Double.

- Few participants felt music would be a good addition to encourage them to work.

  We considered this idea, but did not add music as part of the study as it could bias the results. This could be a great feature to add in future designs.

- Some participants felt the behavior of the avatar is monotonous. While some felt it motivated them to work.

- One participant suggested a Pomodoro Timer to keep them motivated.

  In the initial design of MR, this idea was considered as a way to give breaks in between from the weight of the headset.

Another interesting result that was not expected was that the participants found the task content that they used to type very interesting. The investigators aimed to choose an article that the participants would find monotonous, making the task even more tedious. It was surprising to observe how the participants found the article very interesting and started looking up the article and the author. In fact, few participants read the article throughout the duration of the user study.

5.1 Research Questions

Based on the results of the User Study, we try to answer the Research questions in a better way.

RQ1: Is Body Doubling really helpful? Initially, during the Systematic Literature Review, we did not find many academic findings. But the individuals using body doubling really like it and there are numerous online applications to facilitate video-call based body doubling. Individuals often seemed to be using this technique, even though they were unfamiliar with the name. From the survey, we can say that Body doubling was helpful. A majority of the population who were part of any body-double mode felt the technique motivated them to continue working.

RQ2: What does body doubling mean in MR? How is it different or similar to body doubling in the real world? Through initial research, we found that for body doubling in MR, the user needs to have access to an MR headset and should be comfortable to wear it and work. They would be working alongside a virtual avatar instead of a real person. From the results, we understand that body doubling in MR comes with the added need to work with a headset, which could not be feasible for longer durations. Working in the real world may be simpler without wearing a headset. Nonetheless, there was great interest in the MR mode, and participants seemed to find the virtual avatar intriguing.

RQ3: What are the challenges in the real world, and how can they be improved in MR? In the real world, there is little effort and time required to find a body-double and coordinate a convenient time to work together. A virtual character in MR eliminates this problem, letting the user spend their time in a productive way. Also, connecting with strangers online does not work for everyone. From the user studies we observe there could be issues with using extra screens in the video-call based mode. MR helps eliminate these issues by using a virtual avatar, which can be used any time the user wants to work. It also helps to avoid any distractions when working with body-double in real life.

RQ4: What are the challenges of implementing body doubling in MR? Through the works about designing, we observed that the virtual character and background need to be realistic to give the feeling of co-presence. And the actions of the avatar need to motivate the user to work. From the user studies, a few takeaways to make the MR mode better are: having a little interaction without distracting the user, other forms of productivity techniques such as a Pomodoro timer [8] could be a great addition, as it is easier to procrastinate when using a virtual avatar over time.

5.2 Future Works

The user study can be expanded for a bigger sample size and statistical significance. A few things that could be incorporated into future MR designs are:

1. Adding a few more animations to the avatar, such as a head nod or just looking up at the user when the user looks at the avatar.
2. To make the headset feasible to use, we can have a Pomodoro Timer [8] or similar functionality so that the user can take small breaks at regular intervals of time.
3. The virtual avatar could be brought closer to the user so that the virtual avatar is in the peripheral view of the user.

For the video-call based mode, we can try to make sure that the device showing the body double is not too close to the user's line of sight. This way, the user will not get disturbed with every small motion in the background.

Chapter 6

Conclusions

This research aimed to understand how individuals perceive body doubling in different modes: no body doubling, in-person body doubling, video-call based body doubling, and MR body doubling; and compare it with the no body-double mode and analyze its effectiveness based on the opinions and behavior of the participants.

The user study with 40 participants split among the four modes of body doubling provided insight about participants' behavior. The research contributions are:

1. An overview of the current very low availability of academic work in the field of body doubling, even though the topic is gaining popularity among many users.
2. An overall understanding of body doubling and different modes currently present.
3. Introducing body doubling in MR and presenting the pros and cons of using MR for body doubling.
4. Results of a comparative user study of body doubling in 4 different modes: no body doubling, in-person body doubling, video-call based body doubling, and MR body doubling.
5. nsights about participant needs that could be implemented in future works to improve the current system.

In Chapter 1, the term "Body Doubling" was introduced, and the motivation for this research was defined. An overview of the study was provided to easily understand the work.

In Chapter 2, Review of Literature was done by using PRISMA to perform a systematic review. Through this process, we try to answer the research questions. These questions were defined after the initial narrative review.

In Chapter 3, Design of the User Study was explained in detail. We describe the IRB Procedure, metrics of Data Collected and the MR design.

In Chapter 4, the results of all the metrics that were defined in the design are analyzed and presented.

In Chapter 5, we discuss the results and try to answer further the research questions defined in the beginning. We also propose improvements for future works.

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Appendices

Appendix A

First Appendix