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HP Windows Mixed Reality vs Meta 2: Investigating Differences in Workload and Usability for a Ball-sorting Task

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ABSTRACT: Perceived workload and usability are crucial components of human-computer interactions. Currently, there is a gap in research comparing Augmented Reality (AR) and Virtual Reality (VR) systems for workload and usability. This study attempts to bridge that gap through the comparison of the HP Windows Mixed Reality system and the Meta 2 system for a ball-sorting task. Subjective questionnaires on workload and usability were implemented as comparative measures for three game scenarios of increasing difficulty. Forty-one participants were recruited from the University of Central Florida and its surrounding communities. Results showed significantly lower cumulative total workload and greater usability (for the subscale of ease of use) for the HP Windows Mixed Reality system when compared to the Meta 2 system. There were no statistically significant differences reported for the other usability subscales between the two systems. Also, there were no statistically significant differences in total workload within the three scenarios for both systems. The findings could be attributed to differences in control schemes (i.e., native handheld controllers versus hand gestures), user experience with AR and VR systems, and difficulty of task scenarios.

KEYWORDS: HP Windows Mixed Reality, Meta 2, augmented reality, virtual reality, head-mounted displays, workload, usability, ball-sorting task

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

13.1: 56-66

INTRODUCTION

Throughout recent decades, new technology has emerged that can alter and enhance the way humans perceive the world. Augmented reality (AR) alters a real-world environment by supplementing it with simulated elements; virtual reality (VR) on the other hand creates a completely artificial environment (Chavan, 2016). Both technologies have become areas of interest for academia, industry, government, and consumers alike. Currently, VR technology is more prevalent than AR technology, with VR headsets representing 96.6% of the combined AR/VR market in the first quarter of 2019 ("AR/VR Headsets Return to Growth," 2019). Both AR and VR have diverse applications; AR for example can be used in surgical procedures, training personnel in various fields (e.g., aviation, medical, and military), film making, and interactive gaming (Azuma, 1997). AR and VR share some similarities in terms of general function and purpose with the main difference being the level of artificiality that is incorporated (Azuma, 1997; Chavan, 2016). AR can be used to enhance our perception and understanding of the real world around us by adding graphics, text, or directional cues (Azuma, 1997); conversely, VR uses software to create an artificial environment that replaces the real environment (Chavan, 2016).

Part of making virtual environments (VEs) realistic involves refining how the users interact with the virtual world around them. Over the past several years, varying approaches for hand and finger-based manipulation in AR and VR have been explored. The Rubber Rocks VE involved the user picking up virtual rocks by making a fist and throwing and releasing them by making a flat hand gesture (Codella, 1992). Dorfumuller-Ulhaas and Schmalsteig (2001) presented an AR system that included a marked glove, a stereoscopic computer tracking system, and a 3D model of the human finger allowing for natural grabbing, rotating, and releasing of objects. This current study uses native handheld controllers and hand gestures for object manipulation in a ball-sorting task.

Head-Mounted Displays

A head-mounted display (HMD) offers an immersive pathway for a user to experience AR and VR. Immersion in VR offers a greater feeling of presence or making the user believe they are actually in the VE (LaFortune & Macuga, 2018). Despite occasionally being used interchangeably, immersion and sense of presence are two discrete constructs. Whereas presence in VR refers to the illusory perception of an unmediated experience while in a mediated setting (i.e., feeling as if you are in physically in a simulated environment), immersion encompasses a broader range of engagement in a virtual experience like, for example, losing one's awareness of time from deep involvement in an activity (Hudson, Matson-Barkat, Pallamin, & Jegou, 2019). In AR, immersion is experienced through a combination of a user's ability to interact with both real and simulated elements. As a result of blending elements of reality and simulation, the sense of realism in AR is based on a user's cognition and perception (Shin, 2019). A VR HMD fully covers a user's field of view of the real-world, whereas an AR HMD may not obstruct vision entirely since it still incorporates elements of the real-world (Sutherland et al., 2019). AR and VR HMDs have become increasingly popular due to their ability to simulate dangerous situations with minimal risk (Moss & Muth, 2011). HMDs have been applied to clinical psychology through exposure therapy to treat anxiety disorders (Boeldt, McMahon, McFaul, & Greenleaf, 2019). Each HMD has its advantages and disadvantages. One advantage of modern HMDs, such as the Oculus Rift and HTC Vive, is their accessibility and affordability (Vosinakis & Koutsabasis, 2018). This accessibility offers a wider range of applications in a variety of fields to both professionals and general consumers. Disadvantages of HMDs noted in the literature include heaviness and discomfort: one study using an AR HMD for surgical training noted that surgeons may feel uncomfortable if they were to wear an HMD for up to eight hours during real surgery due to its heavy weight (Chen et al., 2015). The current research aims to expand knowledge on how usability and workload may differ in AR and VR HMD systems.

HP Mixed Reality and Meta 2 HMD Systems

The HMD systems used for this research included the HP Windows Mixed Reality system (hereinafter referred to as HP Mixed Reality) and the Meta 2 system (both HMDs shown in Figure 1). For this experiment, the HP Mixed Reality served as the VR HMD, in which participants used native handheld controllers (see Figure 2 for HP Mixed Reality controllers) to perform the ball-sorting task. In contrast, the Meta 2 served as the AR HMD, where participants used hand gestures rather than controllers to complete the ball-sorting task.

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

13.1: 56-66

Figure 1. HP Windows Mixed Reality System (top image) and Meta 2 System (bottom image).

Figure 2. HP Windows Mixed Reality System controllers.

This comparison raises questions about the usability of each HMD system. The usability of a system refers to its comfort, effectiveness, efficiency, and visual quality. In a usability analysis of the Meta 2 and the Microsoft HoloLens for surgery, the Meta 2 was found to be less effective, despite its broader field of view and higher resolution (Moosburner et al., 2019). The main limitation with the Meta 2 was its tethered design, compared to the wireless Microsoft HoloLens. Additionally, the Meta 2 has had challenges with both hand tracking and environmental mapping, altogether suggesting that the HP Mixed Reality and its native handheld controllers may be more efficient (S. Murphy, personal communication, September 16, 2019).

The manufacturer of the HP Mixed Reality system places emphasis on the ability to immerse a user in a virtual world both comfortably and easily (HP Official Site, 2019). Other VR systems, such as the HTC Vive have been used for medical research and anatomical learning (Egger et al., 2017). Yet, the HP Mixed Reality has not been thoroughly researched for applications in education, medicine or other professional fields. However, the HP Mixed Reality and the Oculus Rift have software plugins available, which could introduce opportunities for non-entertainment applications (Sutherland et al., 2019).

Psychomotor Skills

Understanding how AR and VR affect psychomotor skills is crucial in enhancing the user experience. Psychomotor skills involve activities that require both mental functions and physical movement. The current study investigates the use of psychomotor skills for a ball-sorting task. Gallagher and Satava (2002) investigated the utility of the Minimally Invasive Surgical Trainer Virtual Reality (MIST VR) system as a means of evaluating user psychomotor skills. Results showed that the MIST VR can help distinguish between experienced, junior, and novice surgeons. Kundhal and Grantcharov (2007) conducted a study to validate the role of VR as a tool for assessing laparoscopic technical skills by investigating the correlation between the performance of participants during tasks in the LapSim (a VR laparoscopic trainer) and their performance during an operating room procedure. The study revealed a strong positive correlation between performance for a VR task and performance for the corresponding real-world task, providing solid evidence for the validity of the VR system as an objective tool for assessing surgical skills (Kundhal & Grantcharov, 2007). In addition to realistic interaction,

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

13.1: 56-66

the systems used in VEs also play an important role in overall user experience.

Workload

Workload refers to the cost of completing a task; this cost is a byproduct of human-computer interactions and can be reflected as an attentional, cognitive, or emotional depletion (Hart & Wickens, 1990). Workload can be objectively measured through physiological responses such as brain activity, galvanic skin response and respiration (Brookhuis & Waard, 2010). Workload can also be subjectively measured by participants reporting their perception of workload. Subjective workload is measured through the NASA Task-Load Index (NASA-TLX), a survey that breaks total workload down into six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988). The operational definitions of the six subscales of workload are listed in Table 1. This research planned to investigate the differences in workload between the HP Mixed Reality and the Meta 2 systems.

Term	Operational definition
Mental demand	The amount of mental activity required for the participant to complete a task.
Physical demand	The amount of physical activity required for the participant to complete a task.
Temporal demand	A participant's feeling of time pressure due to the rate or pace at which the tasks or task elements occurred.
Performance	How successful the participant felt in accomplishing the goals of the task.
Effort	How hard the participant had to work to accomplish their level of performance.
Frustration	How insecure, discouraged, irritated, stressed and annoyed the participant felt.

Table 1. NASA-TLX Workload subscale definitions (Hart & Staveland, 1988).

When AR and VR technologies are utilized, how does task workload change? Current research suggests that introducing AR or VR technologies into a task can impact mental workload and performance. Loch, Quint, and Brishtel (2016) showed that an AR-based assistance system, which overlaid demonstrative assembly animations onto a workstation, helped users complete assembly tasks with fewer errors, lower mental workload, and a less amount of time than users assisted by video-based assistance. Another study showed that non-immersive VR training systems help users perform significantly better at simple or complex assembly tasks than users aided by training manuals or multimedia films (Chao et al., 2017). Additionally, AR tablet interfaces have been shown to elicit less mental workload than VR tablet interfaces when used for online shopping with high amounts of auditory and visual stimulation. (Zhao, Shi, You, & Zong, 2017). However, there is little to no research that examines subjective workload when using AR or VR systems to complete a ball-sorting task.

Usability

In addition to workload, usability is another important aspect of AR and VR systems. Usability refers to the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (International Organization for Standardization, 2018). Effectiveness and efficiency are objectively measured through task performance; satisfaction, or the comfort and acceptability of the system, is measured through subjective post-task surveys (Mifsud, 2019). Therefore, in order to evaluate user perception of the two HMD systems, this study focused on measuring satisfaction via a usability survey.

Subjective usability was measured using a survey developed in-house; this survey was adapted from the Usability Metric for User Experience (Finstad, 2010). The survey contained 17 questions relating to user experience. In order to distinguish the different aspects of usability, the survey's questions were classified into four usability subscales: comfort, ease of use, effectiveness, and visual quality. Comfort relates to the user's experience, such as visual discomfort while wearing the HMD. Ease of use describes the users' ability to orient themselves within the environment while wearing the HMD. Effectiveness measures the user's perceived performance of the tasks, as well as determining if the HMD has other applications for real-world skills. Finally, visual quality is defined by

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

13.1: 56-66

the user's perception of visual smoothness, depth, and field of view. In addition to the subscales, the usability survey included open-ended questions. The open-ended questions gauged the participant's positive and negative experience using the HMD systems.

AR and VR HMD systems' growing popularity in a variety of fields, has led to unanswered questions regarding how different HMD systems can affect users' subjective workload and usability. Therefore, the goal of this study was to investigate differences between the HP Mixed Reality system (VR) and the Meta 2 system (AR) regarding workload and usability.

RESEARCH QUESTIONS

The following research questions (RQs) were derived to assist in the evaluation of two HMD systems: The HP Mixed Reality system and the Meta 2 system.

RQ1: Is there a statistically significant difference between the HP Mixed Reality system and Meta 2 system for cumulative total workload?

RQ2: Is there a statistically significant difference between the HP Mixed Reality system and Meta 2 system for subjective usability survey subscales?

RQ3: Is there a statistically significant change in total workload within the three scenarios for the HP Mixed Reality system?

RQ4: Is there a statistically significant change in total workload within the three scenarios for the Meta 2 system?

METHODS

Participants

Forty-one participants were recruited from the University of Central Florida and its surrounding communities. In order to participate, several inclusion criteria were met, which included being a U.S. citizen, having normal or corrected-to-normal vision, no history of seizures, and no color-blindness. Of the 41 participants, 21 were male and 20 were female; the mean participant age was near 22 years old. The males' mean age was 21.95 and standard deviation was 3.25; the females' mean age was 22.21 and standard deviation was 3.58. Individuals were compensated 10.00 USD for their time and travel.

Testbed

Scenarios for the study were developed using the Unity game engine. Unity was chosen to develop the scenarios due to its user-friendly interface and compatibility with multiple software development kits (SDKs). Specifically, the Meta 2 used Meta SDK 2.7.0, while the HP Mixed Reality used the Mixed Reality Portal Version 10.0.17134.1.

Equipment

A standard desktop computer with a 64-bit Windows 10 operating system, an Intel Core i7-8700 CPU (at 3.20GHz) processor, 32 GB of RAM, and an NVIDIA GeForce GTX 1080 Ti graphics card was used for this study. The HP Mixed Reality system used native handheld controllers, whereas the Meta 2 used hand gestures.

Experimental Design

Research questions 1 and 2 focused on a between-subjects design. The independent variable (IV) was the type of HMD system (i.e., the HP Mixed Reality system or the Meta 2 system) and the dependent variables (DVs) were workload and usability survey responses. Conversely, research questions 3 and 4 focused on a within-subjects design. Each system's IV was the ball-sorting scenarios, and each system's DV was the multiple workload surveys.

Interface Training

Prior to beginning the scenario tasks, participants were shown PowerPoint training slides detailing the experiment and how to use the HMD system's control scheme. To inform participants about their condition's control scheme, participants in the HP Mixed Reality condition were shown a slide detailing how to use the two handheld controllers. Participants in the Meta 2 condition were shown slides that informed them how to complete an environmental mapping process, as well as multiple slides detailing gestures to grab and release the balls. After reading through the training slides, participants then completed a practice scenario by sorting 20 balls into red or blue bins in 10 minutes or less.

Scenario Tasks

Participants were asked to complete three ball-sorting scenarios using either the HP Mixed Reality or the Meta

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

13.1: 56-66

2. Both HMDs provided participants with a first-person view of the VE. All participants completed each scenario in the same order, but each scenario was more difficult than the last. Participants in the HP Mixed Reality condition sorted the colored balls using one or two of the native handheld controllers, whereas participants in the Meta 2 condition sorted the colored balls using hand gestures with one or two of their hands (both conditions are shown in figure 3).

Per scenario, the goal was to sort all balls into the correct bin within the 5-minute time limit. In the first scenario, 40 balls were displayed at a size of 0.15m in diameter. In the second scenario, 50 balls were displayed at a size of 0.125m in diameter. In the third, and final, scenario 60 balls were displayed at a size of 0.1m in diameter.

Figure 3. Screenshots of ball-sorting task from the HP Windows Mixed Reality condition (top image), and Meta 2 condition (bottom image).

Surveys

Research surveys were used to measure workload and usability for the ball-sorting task. Additionally, a demographics questionnaire was administered to participants. Descriptions of each survey are presented in the following paragraphs.

Workload Survey

Workload was measured using the NASA-TLX. The NASA-TLX measured workload using six subscales, including the task's mental demand, physical demand, temporal demand, performance, effort, and frustration level. After each scenario, participants took the NASA-TLX and rated their experience with each task on a scale from 0 to 100, increasing in increments of 5, for the six subscales. The use of this survey allowed for the creation of a total workload measure.

Usability Survey

The usability survey was developed in-house; it was adapted from the Usability Metric for User Experience (Finstad, 2010). The survey had four subscales that encompassed visual quality, comfort, ease of use, and effectiveness. The participants were asked to rate their experience on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). In order to test the survey reliability, the researchers conducted a Cronbach's alpha test which yielded .86. This value is considered acceptable and therefore the survey was deemed reliable (Pallant, 2016).

Demographics Questionnaire

The demographics questionnaire consisted of a series of general background questions, such as age, and gender education level, as well as specific questions related to technology usage (e.g., previous VR use and time spent playing computer/video games).

Procedure

The experiment procedure is listed in Table 2.

RESULTS

The data was collected and analyzed using the Statistical Package for the Social Sciences (SPSS) version 24. A Kolmogorov–Smirnov (KS) test was used to test for normality on workload and usability. Results of the KS test showed that the data violated the assumptions of normality. Additionally, a test for homogeneity of variance, as well as an analysis for outliers, was conducted. Researchers abstained from removing the two outliers found upon visual inspection of the scatterplots. Since the data violated assumptions of normality, the Mann-Whitney U Test and Friedman Test were used as

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL
URJ
13.1: 56-66

Section	Task Completed
Pre-Scenarios	1. Informed consent 2. Color-blindness test 3. Demographics questionnaire 4. Interface training
Scenarios	5. Scenario 1, one-minute break, workload survey 6. Scenario 2, one-minute break, workload survey 7. Scenario 3, one-minute break, workload survey
Post-Scenarios	8. Usability survey 9. Receipt for compensation 10. Dismissal

Table 2. Experiment Procedure

nonparametric tests.

For RQ1, statistically significant differences were found between the HP Mixed Reality and the Meta 2 for cumulative total workload (i.e., the three total workload survey scores). A Mann-Whitney U test revealed total workload was higher for the Meta 2 for all three scenarios (see Table 3).

For RQ2, results showed a statistically significant difference for the usability subscale of ease of use between the HP Mixed Reality (Md = 4.25, n = 20) and Meta 2 systems (Md = 3.5, n = 21), U = 105.5, z = -2.58, p < .05, r = .41. There were no statistically significant differences reported for the usability subscales of comfort, effectiveness, or visual quality.

The Friedman Test revealed no statistically significant differences in total workload within all three scenarios for the HP Mixed Reality (RQ3). Similarly, the Friedman Test indicated no statistically significant differences in total workload within all three scenarios for the Meta 2 (RQ4).

Head-Mounted Display			Mann-Whitney U Test			
Total Workload	**HP Mixed Reality**	**Meta 2**	***U***	***z***	***p***	***r***
Scenario 1	(Md = 9.58, n =20)	(Md = 32.5, n = 21)	U = 66.5	z = -3.75	p < .05	r = .59
Scenario 2	(Md = 9.58, n =20)	(Md = 32.5, n = 21)	U = 68.5	z = -3.69	p < .05	r = .58
Scenario 3	(Md = 10, n =20)	(Md = 35.83, n = 21)	U = 83	z = -3.32	p < .05	r = .52

Note. A Mann-Whitney U test was conducted to compare total workload between the HP Mixed Reality and Meta 2 conditions for each of the three scenarios.

Table 3. Research Question 1 Results

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

13.1: 56-66

DISCUSSION

RQ1: Is there a statistically significant difference between the HP Mixed Reality system and Meta 2 system for cumulative total workload?

The results for RQ1 showed a statistically significant difference in total workload across all three ball-sorting task scenarios between the HP Mixed Reality and the Meta 2. Therefore, the HP Mixed Reality was shown to induce less cumulative total workload when compared to the Meta 2. Although the exact origin of this difference in cumulative total workload is unclear, an influential factor could be the type of control scheme (i.e., native handheld controllers versus hand gestures) for the AR and VR HMD systems. The authors concluded that previous exposure to handheld controllers could have influenced the participant's level of familiarity with similar technologies and in turn, potentially affected their perceived cumulative total workload.

RQ2: Is there a statistically significant difference between the HP Mixed Reality system and Meta 2 system for perceptual usability survey subscales?

Results for RQ2 showed a statistically significant difference in the usability subscale of ease of use between the HP Mixed Reality system and the Meta 2 system. Participants may have had more experience with VR systems than with AR systems. This assumption may be supported by the popularity of VR HMDs, which accounted for 96.6% of the AR and VR market in the first quarter of 2019 ("AR/VR Headsets Return to Growth," 2019). Further, past research by Agarwal and Prasad (1999) found that prior experience with similar technology is positively correlated with perceived ease of use. Therefore, previous experience with VR systems could have attributed to the significant difference in ease of use.

Ideally, the demographics questionnaire would have been able to provide more information regarding technology usage. A closer look at the demographic questionnaire revealed questions related only to previous VR usage. It is unclear as to the level of AR experience the participants had prior to the study. Similar to RQ1, control scheme (i.e., native handheld controllers or hand gestures) could have been an influential factor. Participants may have found it easier to use the HP Mixed Reality's native handheld controllers, rather than the Meta 2's hand gestures, due to the provided tactile feedback, which may mirror the feeling of physically sorting the balls.

There were no statistically significant differences among the usability subscales of comfort, effectiveness, and visual quality between the HP Mixed Reality and the Meta 2 systems. Therefore, what additional factors may be considered when choosing between the HMD systems? A primary factor in choosing an HMD system is cost. The HMD systems differ considerably in price: at the time of writing, the retail value for the Meta 2 is approximately 1299.00 USD, whereas the HP Mixed Reality system is approximately 179.00 USD (Amazon, 2019). A secondary factor to consider is that both HMD systems require additional equipment to operate, specifically a desktop computer with high processing power. A tertiary factor to consider is accessibility: the HP Mixed Reality is available through a variety of sources (i.e., online third-party vendors, the manufacturer, and physical retail stores) in contrast to the limited availability of the Meta 2 (i.e., online third-party vendors only) due to its discontinuation.

RQ3: Is there a statistically significant change in total workload within the three scenarios for the HP Mixed Reality system?

The results for RQ3 revealed no statistically significant differences in total workload across all three scenarios for the HP Mixed Reality system.

RQ4: Is there a statistically significant change in total workload within the three scenarios for the Meta 2 system?

The results for RQ4 revealed no statistically significant differences in total workload across all three scenarios for the Meta 2 system.

One possible explanation for these nonsignificant differences in total workload across the three scenarios for both HMDs is the non-substantial increase in the number of balls for each scenario. Specifically, the number of balls increased by only 10 for each scenario, perhaps resulting in marginal changes in difficulty between scenarios 1 through 3. Additionally, the balls shrunk in size by .025 m in diameter each scenario as participants progressed from scenario 1 through 3. Perhaps a greater decrease in diameter for the balls between scenarios 1 and 3 would present a more difficult challenge as the scenarios progressed.

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

13.1: 56-66

Additionally, a lack of time to gain familiarity with both control schemes (i.e., native handheld controllers or hand gestures) may have led to the lack of statistically significant differences in total workload between scenarios. Perhaps, as scenarios progressed, participants would master the HMD systems' control scheme, which would in turn decrease total workload. However, results indicated no pattern of difference in total workload. This lack of a trend in the data could possibly be accounted by an inconsistency in strategy for each ball-sorting scenario. Specifically, some participants in the Meta 2 condition used both hands but other participants used one hand at a time.

LIMITATIONS

A shortcoming of the study is the absence of AR experience questions on the demographics questionnaire. Since the experiment centered on the differences between AR and VR HMD systems, it may have been beneficial to have information on both AR and VR experience. Another shortcoming was a lack of clarity in the Meta 2 interface training on using hand gestures; specifically, information detailing that both hands can be used to complete the scenarios. Adding this information, alongside a free-play practice scenario (i.e., a scenario in which a participant could interact with the environment without a task to complete), could eliminate confusion in using hand gestures to sort the balls.

CONCLUSION

This study highlights the differences in workload and usability between the AR and VR HMD systems chosen for a ball-sorting task. When investigating workload and usability for a ball-sorting task, the HP Windows Mixed Reality System yielded significantly less cumulative total workload and significantly higher ease of use than the Meta 2 system. These significant differences found between the two systems suggest that the HP Windows Mixed Reality is an easier-to-use HMD system for sorting and object manipulation tasks. Furthermore, this utility for sorting and object manipulation tasks displays the practicality VR systems demonstrate for assembly training, exposure therapy, and interactive entertainment. In contrast, the authors infer that the significantly higher cumulative total workload and lower ease of use perceived for the Meta 2 system may have been attributed to unfamiliarity with using hand gestures to interact with virtual objects. Despite the challenges of the Meta 2 system for the ball-sorting task, AR systems have shown promise for use in online shopping, aviation training, and surgical procedures. Altogether, there is a need to reduce workload and improve usability of AR and VR systems in order to optimize performance and enhance user experience.

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THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

13.1: 56-66

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