Analysis of Haptic Feedback and its Influences in Virtual Reality Learning Environments

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***Abstract*—In this work we present our approach of measuring the influence, importance and immersion of haptic feedback in a virtual reality learning environment. Participants were given the goal to improve themselves to their best ability on a task involving virtual weights supported by real world objects in a mixed reality environment. Conducting pre- and post-surveys, assessing the immersion and putting the resulting data in comparison with the test group, which used a pure virtual reality environment. We found correlations bolstering our initial assumption of the importance of haptic feedback in understanding and usage of virtual reality learning environments for specific functions.**

***Index Terms*—virtual reality, visualization, virtual learning environment, haptic feedback**

I. Introduction

Virtual Reality has been defined as I^3 for "Immersion-Interaction-Imagination" [1]. Possible interaction components of this high-end user interface involves visual, auditory as well as haptics. Since the dawn of virtual learning environments (VLE) [2]–[4], virtual- and augmented reality, haptic feedback, a design element for human-computer interfaces and how it can be best utilized in interactive applications, is of special interest. Virtual Reality (VR) makes it possible to immerse the learner into a VLE that is enhancing, motivating and stimulating learners' understanding of certain events [5], [6]. Interactive VLE's have shown the ability to transmit physical phenomena surpassing traditional learning methods [7], [8].

Haptic feedback encompasses the modalities of force feedback, tactile feedback, and the proprioceptive feedback [9]. Force feedback integrated in a VLE provides data on a virtual object hardness, weight, and inertia. Tactile feedback is used to give the user an impression of the virtual object surface contact geometry, smoothness, slippage, and temperature. Finally, proprioceptive feedback in the sensing of the user's body position.

In various simulation systems, haptic feedback has become an integral component. Moreover, in systems designed for teaching surgical skills [10]–[12], haptic feedback is considered to be essential to conceptualize and segment most neurosurgical procedures into critical task components. Haptics in nearly all such VLEs have been designed to realistically replicate the real-world forces relevant to a particular task. Earlier works suggest that haptics in a VLE contribute positively to the users' learning outcome [13] and perception of virtual object shapes [14]. Contrary to that, Adams et al [15] found no significant learning benefit from haptic feedback for simple manual assembly task, but an overall benefit from training in a virtual environment.

Although intuitively appealing, the true benefits of haptic (VLE training) platforms are unknown. To further expand to that question, whether haptic feedback contributes to the learning outcome, as well as to assess the immersion in comparison with plain virtual feedback, we developed a virtual reality test environment which satisfies a simple mechanical task to throw objects towards a target. Over the course of the testing, the object shape and weights, as well as the target distance was changed for two groups; both being exposed to the VLE, but one group was handling with real objects, while the other one just had a virtual representation of such.

II. Methodology

Our basic premise was to identify a simple task which can be employed into a VLE. There we could introduce haptics for one group and non-haptics for a control group without changing any other simulation components. For that, a throw-and-hit assignment for VLE participants was conceptualized, where we are able to utilize haptics by having virtual objects for one testing group and real objects for the other one: Both groups used a VR headset and found themselves in a virtual environment, see Fig. 1. One group, referred to as mixed reality group (MR) threw real wheights, with an electronic trigger on the VR controller to check when they threw the weight. The other group, referred to as virtual reality

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group (VR), on the other hand, had virtual weights only. We conducted our research for this study with a participants group of size n = 55. In order to find differences in learning experience between pure VR and MR with haptic feedback, we had our participants engage in two different versions of our research simulation. The different versions and setup will be discussed in Subsection II-2. We tested 40 participants in the MR and 15 in the VR group. The reason for this is the nature of the improvised environment, especially the copper conduction to check a throw in MR, which did not always work properly and a consequential frustration could bias the results. To level out these fluctuations, we put more participants into the MR group. To gain a measurable outcome we created a Virtual Learning Environment resembling a soccer stadium (see Fig. 1). "Learning" in the further course of this work relates to the improvement of accuracy and so gaining of intuitive experience of each participant. In this virtual stadium all participants were given the general task of throwing objects into targets multiple times while trying to improve themselves to the best of their ability. For further insights on how the immersion is being influenced by haptic feedback we had each participant complete a survey before and after the VLE experience (see Section II-5). Due to the setup being used indoors in a lab environment as well as outdoors on a sports field, it was necessary for the simulation to run on two devices. We used a Windows PC with an Intel Core i7 4770K processor and a NVidia GeForce GTX 1070 graphics card for testing on the field and a Windows PC with an AMD Ryzen 7 and a NVidia GeForce GTX 1080Ti in the lab. Both setups used the HTC Vive HMD as immersive display with the corresponding modified controller as seen in Fig. 2.

Fig. 1. View of the participant in the VLE with example objects on the left, target in front and information blackboard on the right.

1) Testing Approach: In order to get comparable values, each participant was placed at the same position in the stadium and given some time to get accustomed to the environment. The testing was started by supervisor interaction and afterwards run by the participant. The task was to take a virtual object (see Table I) and throw it to a target that spawns in front of the participant on the field. The targets were divided into four sections to give the user visual feedback as well as to include gamified gained points calculation to increase motivation. The distance varied randomly for each section between 8ft and 50ft. Each section required 5 throws. Information about the last throw such as strength and angle were displayed on a blackboard on the right side of the test field and participants were encouraged to use this information for help if necessary. After each throw some data (see Section II-3) was saved by the simulation and at the end of each test run, everything was written to a file in JSON format including the participants ID. The weights were chosen to be reasonable within a margin for participants to throw with one hand. For each weight/distance pair, the participants need to intuitively pre-calculate the necessary force on the weight to hit the target. Whether or not real weights add to ones immersion and positive feedback in comparison with a full virtual environment is the given research question.

Fig. 2. Left picture shows the empty glove controller that was used during testing. Right picture shows an example how the baseball is held and therefore sending a signal to the simulation.

TABLE I
WEIGHTS

Type	MR	VR
Baseball	0.34lb	virtual
Weight Disc #1	0.5lb	virtual
Weight Disc #2	1.0lb	virtual
Weight Disc #3	2.5lb	virtual

2) Controls: To create a more realistic interaction with the simulation, we modified the controller of the HTC Vive. In order to let participants forget that they are actually using controls, we used a common cloth glove and stitched the modified vive controller on it. This glove and the controller have been attached with soft tape to the participants arm in order to prevent it from moving or falling off during the process of a throw movement. We used thin electric cables that were welded inside the controller on the positive and negative contacts of its trigger; these cables were attached to the glove with copper tape to ensure connectivity (see Fig. 2). With this preparation the participants were able to simply tip their index finger and thumb together to send a signal to the simulation. In order to have reasonable haptic feedback for throwing tasks, the testing for MR was conducted on the lower sports complex on Cal Poly campus. This was necessary to prevent accidents or broken glass by throwing weight discs or baseballs. All throwable objects, meaning the baseball and all different types of weight discs, were wrapped with the same conducting copper foil as was the gloves on the controller. Hence, as soon as the user picked up the object it spawned in the simulation at their hand position. In comparison to the MR group, VR participants only had to wear the glove but did not get any weights. They had to interact with pre-spawned virtual objects and just close the connection with their index finger and thumb on the objects position to attach it to their hand. Both version would then move their arms in a manner how they would normally throw and the movement of the controller got tracked and hence the appropriate velocity and direction for the virtual object could be calculated.

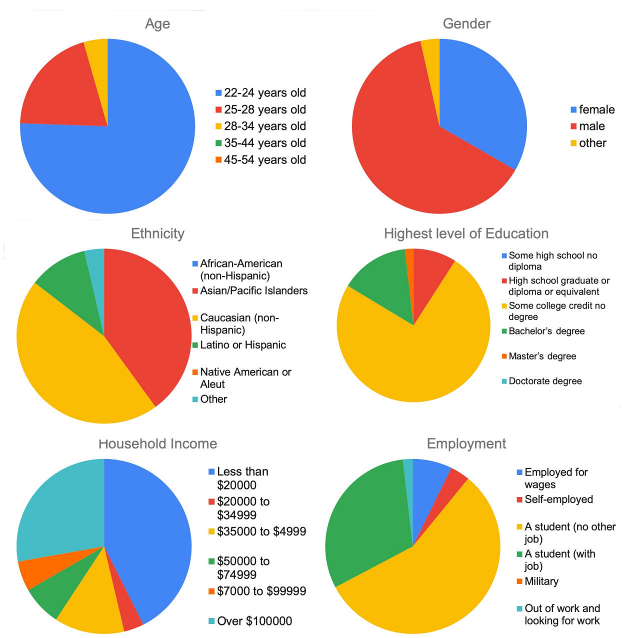

Fig. 3. Participants demographics. Distribution of the participants age, gender, ethnicity, education, household income and employment.

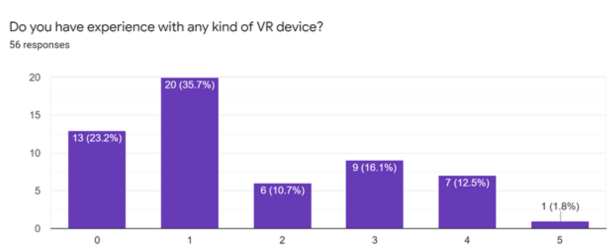

Fig. 4. VR experience of the tested group: We asked about the level of VR experience on a scale from 0 (not at all) to 5 (a lot).

3) Data acquisition: For each throw various data points were saved for later analysis. Those data points included first and foremost the distance between the target and the impact point of the object with the ground, the type of object, sequence number of the throw as well as applied force and release angle of the object.

4) Restrictions and Limitations: Due to the makeshift origin of the participants controls we sometimes encountered problems with connectivity between the controller and the object during the test sessions. We anticipated that this issue might negatively affect gained immersion, hence we kept this in mind while analysing the results. Unfortunately, due to an undiscovered bug in earlier versions of the simulation we had to delete some single invalid data points, and their negative consequences on the learning curve of some data sets needed to be excluded from our analysis.

5) Questionnaire: Participants were required to fill a pre and post questionnaire respectively before and after experiencing the VLE. The pre questionnaire collected demographics, the post questionnaire assessed immersive attributes after finishing the tasks in the VLE. The post questionnaire was structured in the form of the Game Experience Questionnaire [16]. It contained questions for "during" the VLE which included competence, sensory and imaginative immersion, flow, tension or annoyance, challenge as well as positive or negative effects. The questions regarding "after" the experience in form of the Game Immersion Questionnaire [17] assess the attributes attention, temporal dissociation, transportation, emotional involvement, challenge and enjoyment.

III. Tested Group Demographics

Our testing group consisted of n = 55 participants overall who were divided into MR (40) and VR (15). As seen in the demographics in Fig. 3 the groups demographics are diverse and distributed evenly among both groups. Further on we raised the question regarding VR experience as can be seen in Fig. 4. The group consisted thoroughly of students and Alumni. 74.5% have Computer Science as their major, 10.9% study a crossover of Computer Science and Art, 7.2% study Electrical Engineering and 5.5% are studying Art.

IV. Results

A. Throw Data

The acquired data from our participants indicate, that on average, the distance (difference of the impact point to the target center) and improvement assessment (shortening or lengthening the distance over time) for both groups are strikingly similar as can be seen in Fig. 5 and the small variances are in regards to the standard deviation statistically irrelevant. However, there is an observable increased improvement outcome for MR participants in certain conditions during the simulation, which is more prominently pronounced when taking a look at the improvement for each single weight object as can be seen in Fig. 6.

The distance, as well as improvement for each weight is displayed in this figure and shows a very distinct trend: For lighter weights, the MR participant initially showed a better distance to target outcome ("Baseball #1" and "Weight 0.5 lb"). A similar result was seen when the object's weight was reduced compared to the previous object (from "Weight 2.5lb" to "Baseball #2") in comparison with the VR group. In contrast to that, bigger weights resulted in a greater distance

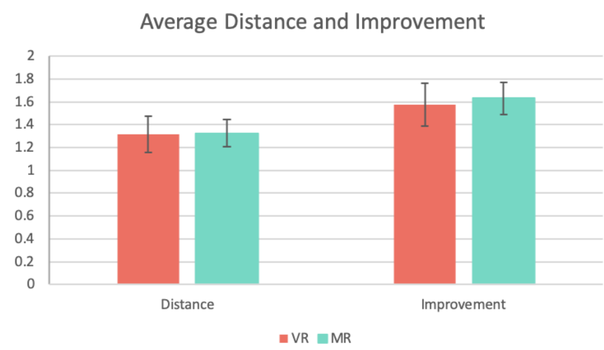

Fig. 5. Average Distance and Learning of all Participants: (red) for VR and (cyan) for MR participants.

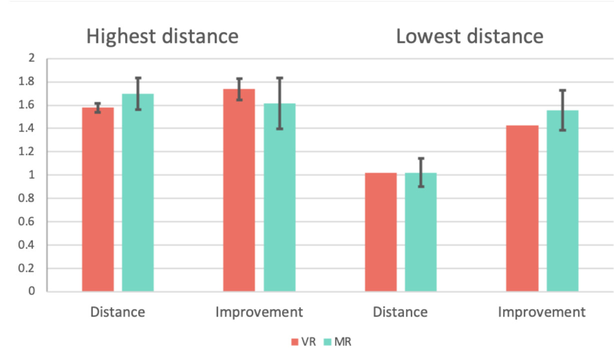

Fig. 7. Average Distance and Learning for most and least accurate participants: (red) VR and (cyan) for MR.

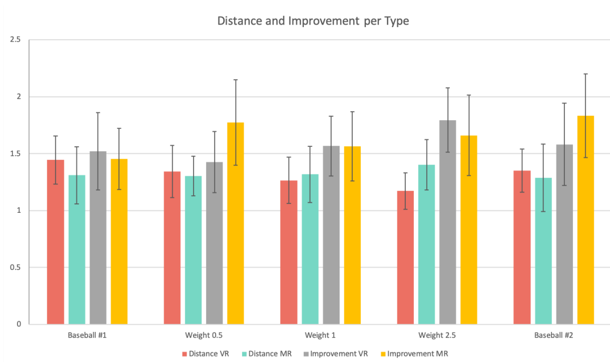

Fig. 6. Average Distance and Learning per different object/weight type: (red) distance in VR, (cyan) distance for MR, (grey) improvement for VR and (yellow) improvement for MR.

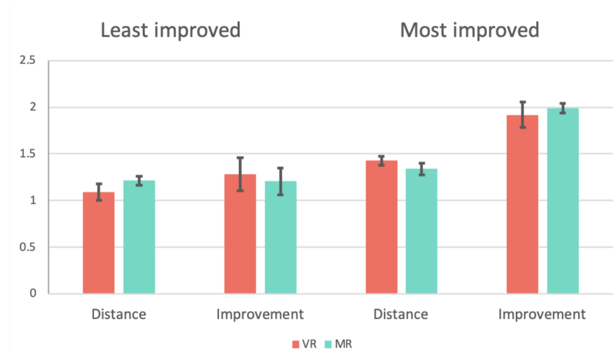

Fig. 8. Average Distance and Learning for best and worst improving third of our testing group. (red) VR and (cyan) MR participants.

to the target center than for the VR participants, and the improvement was lower as well (”Weight 1lb” and ”Weight 2.5lb”). Based on direct verbal feedback of our MR group, we conclude, that the handling of bigger weights is perceived unwieldy. However, the MR group showed a higher learning in comparison to the VR group whenever a larger weight change was instructed.

Further on, we investigated the outcome for the best and worst performances in regard to distance to the target, as well as improvement. Comparing the average distance and the improvement outcome of the upper and lower third of aiming performances in Fig. 7, the similarities are still noteworthy, although the improvement for VR participants has a less pronounced standard deviation for best and worst, an effect which is to be found reversed in comparing the best- and worst third improvements as can be seen in Fig. 8, but still governed by comparable values. A slight trend can be observed, showing a trend that the best accurate participants would improve their accuracy more in MR, while the worst accurate participants show a greater improvement in VR. We found that this correlates well with the immersion feedback we received from the Game Experience Questionnaire which we will discuss in the next subsection.

Overall, we could not observe any statistically relevant variance in our data, which would underline a notable different performance or improvement result for either group. While there are trends regarding the standard deviation, the results do not indicate any particular improvement of our MR testing group. Note, that we tested a simple mechanical movement, which requires only a basic skillset: throwing objects towards a target. Triggering the let-go point with a simple switch is proven to be effective in games, and works similar in our VR testing environment. Consequently we did not expect better performing MR participants, but the similarity in improvement was unforeseen. A closer investigation in their perceived immersion followed.

B. *Immersion*

Conducting the Game Experience Questionnaire to assess the immersion during the VLE experience followed by the Game Immersion Questionnaire do measure the immersion felt after the testing, one can recognise a similar outcome as can be seen in Fig. 9.

While there are small variations such as a tendency for MR to feel more involved and also competent during the experience but also claim a slightly higher stress value, we understood that MR participants had to concentrate on a lot more things at the same time to fulfill the given task of hitting the targets. While having a weight in their hand improved their intuition for their interaction it also required additional attention. They

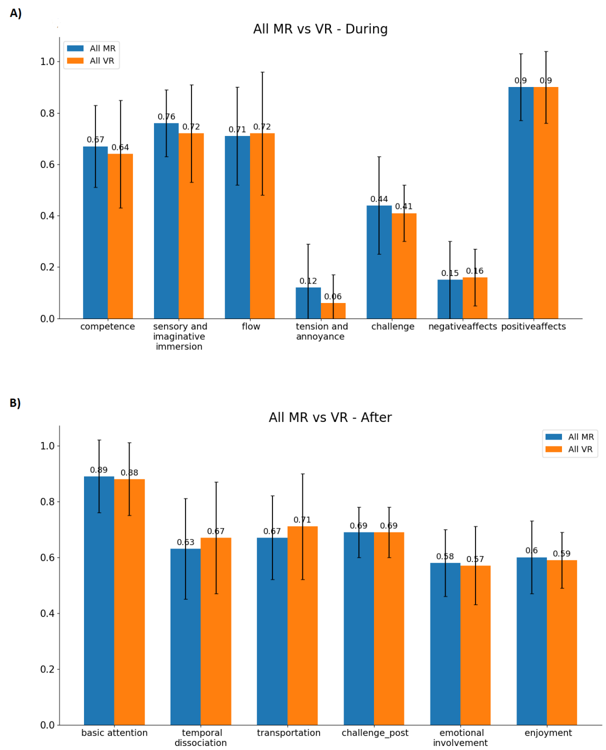

Fig. 9. Average immersion before and after the VLE experience: (blue) MR and (orange) VR group. Each value is in the range from 0 (not at all) to 1 (absolutely).

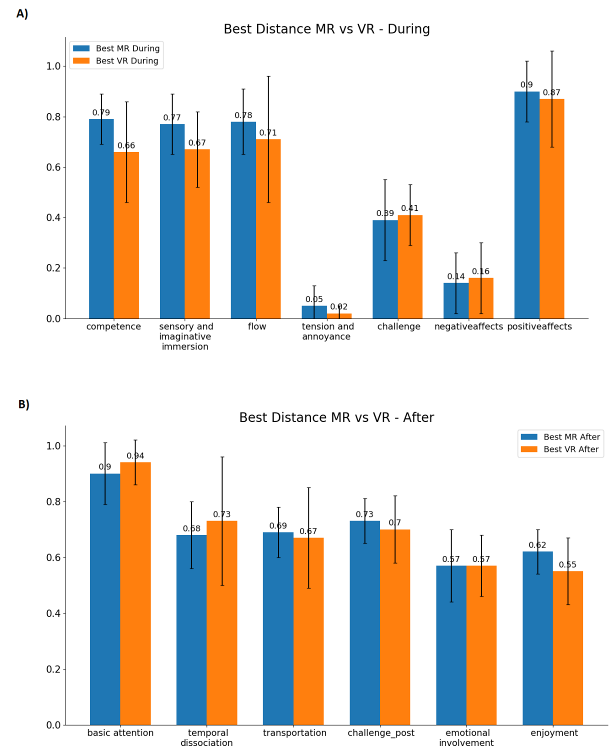

Fig. 10. Immersion values for the best third aiming performances during and after simulation: (blue) MR and (orange) VR group. Each value is in the range from 0 (not at all) to 1 (absolutely).

also had to focus on holding and releasing the objects in the correct manner, as opposed to the VR group where holding their fingers together was very much resembling the simplicity of pressing a button on a common controller. However, these variations in the given data are small and considering the standard deviation displayed in Fig. 9, of minor significance.

Taking a better look into the best third performances in regards to aiming, the Game Experience Questionnaire delivers notable deviations shown in Fig. 10a. Here we see the immersion values during the experience are distinctively increased and above the standard deviation for accurate MR participants. It is interesting to note that Fig. 13a showing an overall better immersion for MR during the simulation also indicates better attention to fulfil the task at hand, even though the average outcome does not support this. In contrast to this findings, Fig. 13b shows similar data points for the immersion perceived after the VLE experience. We interpret this trend as a result of the sense of accomplishment, which could be found in both groups due to their similar performances.

Among the third of participants with the highest measured rate of improvement, those in the MR group reported a higher average immersion for sensory and imaginative immersion as well as flow and transportation than those in the VR group, see Fig. 11a and 11b. The levels for competence, tension and annoyance, challenge and positive/negative effects, basic attention, temporal dissociation, challenge perceived after the VLE experience, emotional involvement and enjoyment vary only statistically insignificant. However, the strong difference in the standard deviation for enjoyment and especially negative effects is noteworthy and a result of frustration for handling the heavier weights in virtual reality. This trend was present both during and after the simulation as seen in Fig. 11a and 11b.

Investigating the immersion for the worst third performer in regards to closing the distance to the target, only the basic attention has a significant higher basic attention for the MR group, which is explainable due to the increased required concentration when handling real objects for those with less skills for accuracy. This can be seen in Fig. 12. All other immersion indicators show a similar behavior for both groups. Thus, participants whose average distance to the target was in the lower third of all participant reported noticeably higher tension and challenge scores than those in the upper third-especially in MR.

As for the lower third of improvement seen in Fig. 11 and 13, compared to those in the highest third of learning displayed in Fig. 11a and 11b, those in the lowest third reported higher sensory immersion and basic attention for the MR group, and higher sensory immersion, flow, challenge, temporal dissociation, transportation, emotional involvement, and enjoyment for the VR group, underlining the principle trend for handling real weights.

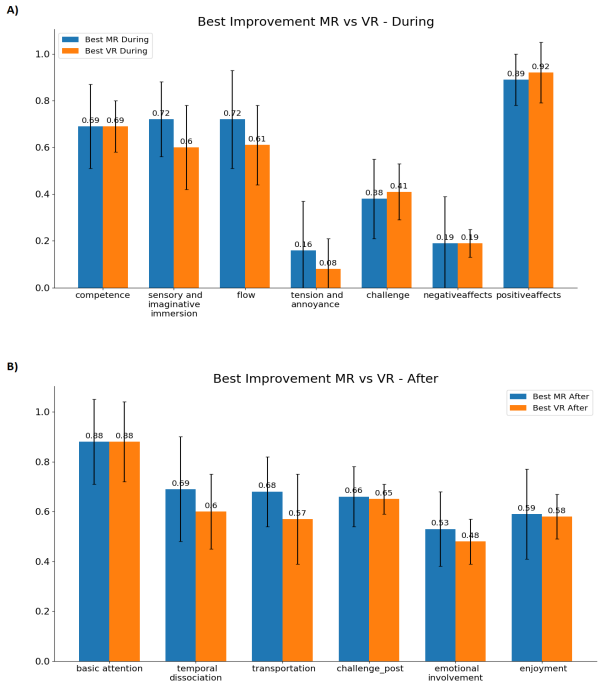

Fig. 11. Immersion values for participants with the best third improvement outcome during and after simulation: (blue) MR and (orange) VR group. Each value is in the range from 0 (not at all) to 1 (absolutely).

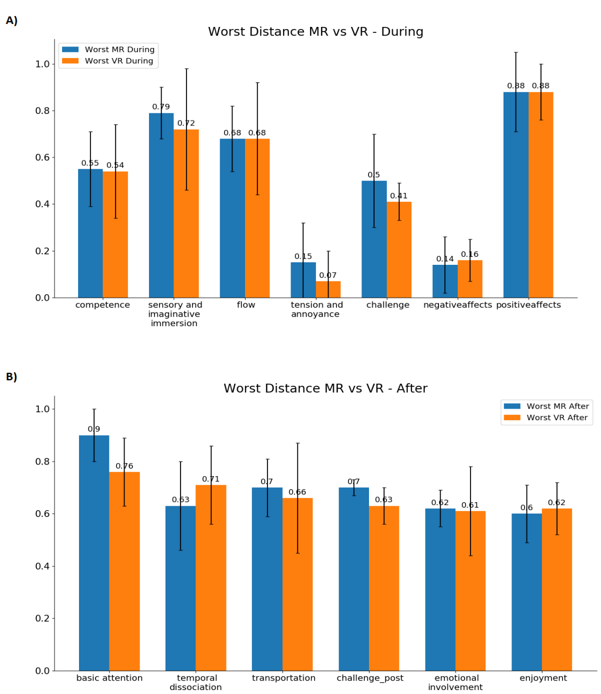

Fig. 12. Immersion values for the worst third distance during and after simulation: (blue) MR and (orange) VR group. Each value is in the range from 0 (not at all) to 1 (absolutely).

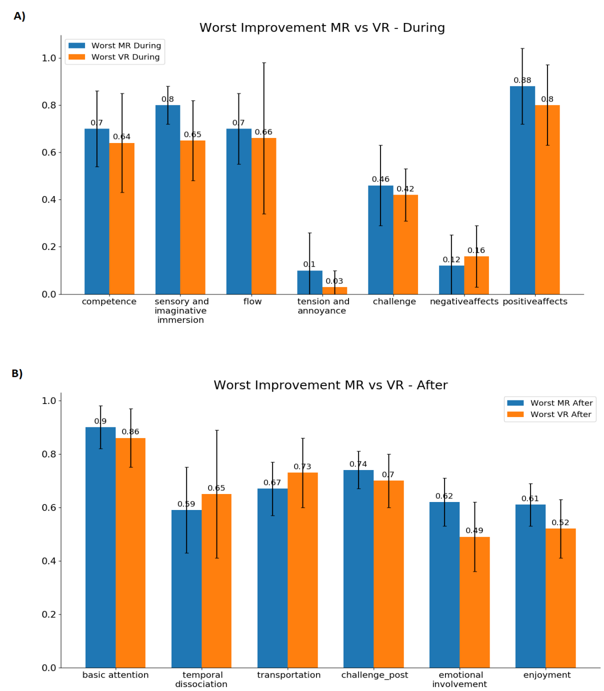

Fig. 13. Immersion values for the worst third learner during and after simulation: (blue) MR and (orange) VR group. Each value is in the range from 0 (not at all) to 1 (absolutely).

V. Conclusion

Overall, our experiment found that neither learning in a mixed reality environment compared to learning in pure virtual reality was strictly better than the other under the restriction of our experiment, by investigating a simple mechanical task. We were able to see improvement in some areas, such as with less heavy weights, but the unwieldy nature of the heavier weights, combined with the unfamiliarity of throwing such an object, caused too much interference in mixed reality to properly measure learning- an issue that was not present in pure virtual reality. However, a general trend for higher immersive values was observed for the MR group, which is explainable for handling real objects. Future experiments may want to use objects that participants are more used to throwing. At present, our findings show that in comparison, haptic feedback for simple tasks such as throwing weights, does not provide enough advantages to justify the extra cost and complications of setting it up, but perhaps in the future with better technology we can improve results.

VI. Future Work

One of our main concerns regarding the outcome of our analysed data was the anticipated skew because of issues in usability of the available tools. Even though we could identify tendencies for some parts of our tested application, like the better immersive feeling in MR when changing weights of thrown objects, we intend to continue the research on this topic with more sophisticated controls and more exactly formulated tasks. Those could include a number of techniques or specific movements involved in surgery or fitting games without the common help of artificially adjusted placement to overcome inaccuracies of any means of controls.

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