THE EFFECTIVENESS OF VIRTUAL REALITY TRAINING FOR ARM PROSTHESIS CONTROL COMPARED WITH PROSTHESIS SIMULATOR TRAINING

Bart Maas[a], Jack Tchimino[a], Bram van Dijk[a], Alessio Murgia[a], Corry K. van der Sluis[b], Raoul M. Bongers[a]

[a] *University of Groningen, University Medical Center Groningen, Department of Human Movement Sciences, Groningen, The Netherlands*

[b] *University of Groningen, University Medical Center Groningen, Department of Rehabilitation Medicine, Groningen, The Netherlands*

ABSTRACT

Background: It would be beneficial for people with an upper limb amputation to be able to start prosthesis training at an early stage during their rehabilitation process. Virtual reality can be used to provide early access to training. The current paper evaluates the differences in effectiveness of training using virtual reality and training using a prosthesis simulator.

Method: Twenty able-bodied participants were included and randomly divided into two groups, the VR (virtual reality) and the SIM (prosthesis simulator) group. Both groups completed a pre-test / post-test design with five training sessions in between. The effectiveness of the training was measured during the pre-test and post-test by using 3 standardized tests, the Box and Blocks test, the Southampton Hand Assessment Procedure (SHAP) and the Cylinder test.

Results: Both groups improved from pre-test to post-test and almost no statistical differences between groups were found. Only in a bimanual task from the SHAP the SIM group significantly outperformed the VR group.

Conclusion: No distinct differences between both groups were found in the majority of the tests, which shows that virtual reality training does not differ in effectiveness from prosthesis simulator training. However, virtual reality training is novel which is why motivational aspects and patient training should be explored in future research.

INTRODUCTION

Prosthesis training would preferably start at an early stage during rehabilitation to practice functional skills and to experience actual prosthesis use. Incorporating a virtual reality environment in rehabilitation practice can offer such an early training. A virtual environment where people with a recent amputation experience what it is like to use a prosthesis in daily tasks could prepare them for when they receive their personal device. Such an environment can also have variable difficulty settings to ensure motivation for training. Furthermore, in virtual reality individual feedback can be given to the user to assist during training. However, the question needs to be asked whether virtual reality and real life training provide different experiences and might be different in their effectiveness. The research question in the current paper is what the difference in the improvement of functional prosthesis control is between training in a virtual reality environment and training with a prosthesis simulator.

METHOD

Design

A pre-test post-test design with two experimental groups, the Virtual Reality (VR) group and the Simulator (SIM) group, was used. Before the start of the experiment, participants provided written informed consent. Participants were randomly assigned to one of the two groups before the start of the experiment. Each group trained for five training sessions on consecutive days between the pre-test and post-test. The pre-test and post-test were identical and included three tests which measured how skilled participants were in using the upper limb prosthesis simulator (Figure 1A), which resembled actual prosthesis use. The simulator consisted of a brace with an elbow joint which was connected to the upper arm and forearm using Velcro straps. The prosthesis, a Bebionic hand (Ottobock

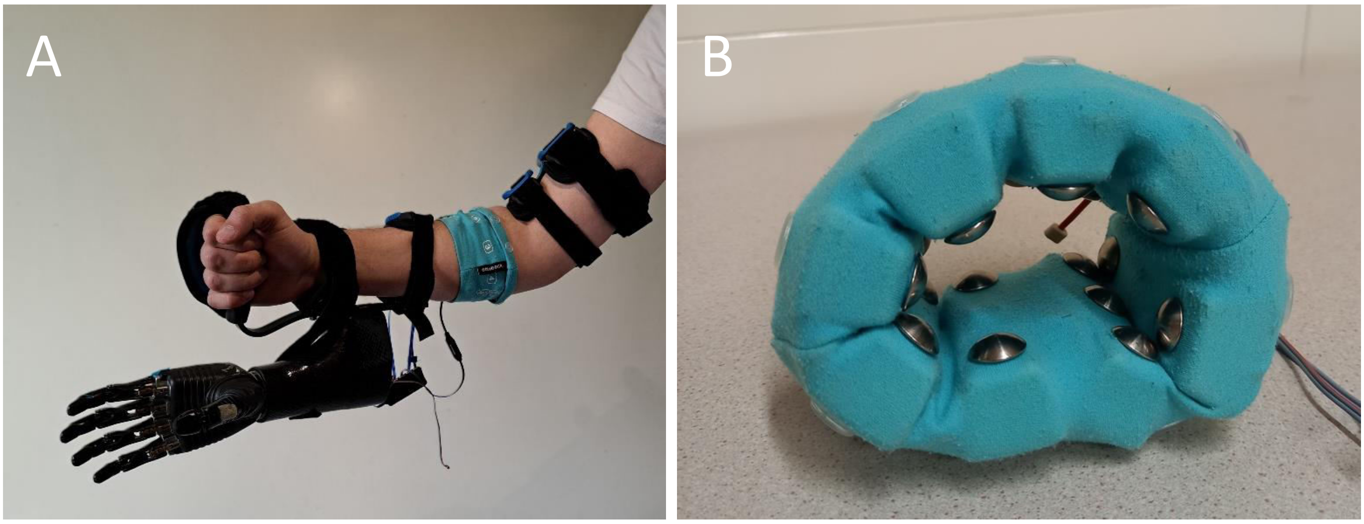

Figure 1. A: The prosthesis simulator controlled by the MyoPlus system which uses pattern recognition control. B: The cuff comprising the Ottobock MyoPlus system used to control the virtual prosthesis in the virtual reality environment

Healthcare Products GmbH, Austria), was attached underneath the brace of the forearm. The hand was controlled using the MyoPlus system (Ottobock Healthcare Products GmbH, Austria), which operates using pattern recognition. The virtual prosthesis was controlled using the same control scheme as the real prosthesis using the MyoPlus system from Ottobock (Figure 1B).

The tests included in the pre-test and post-test were the Box and Blocks test [1], the Jar Lid task and the Zipper task from the SHAP [2] and the Cylinder test [3], [4].

Training protocol

The VR group trained for five sessions within the virtual immersive environment, which was designed to be game-like. The setting of the game was that the user plays as a barista in a Mediterranean coffee shop. Participants had to complete a waitress's orders by choosing the correct cup and the correct button on the machine using the virtual prosthesis (Figure 2). They then needed to move the cup to the tray while trying not to spill any liquid. After an order was completed, the participants received a reward based on their performance in the form of coins. Dependent on the type of cup, the gasping force could deform or break the cup when too much force was applied. The game provided the user with relevant feedback on the amount of force they applied when a cup was grasped. This force feedback was provided in the form of a horizontal bar with a slider which indicated the amount of force applied by the prosthesis (Figure 2B).

The SIM group also trained for five training sessions performing a task similar to the VR group except using the prosthesis simulator in a real world setting, mimicking the virtual environment. A training set-up was built closely resembling the outlay of the VR coffee shop. Participants had to use the prosthesis simulator to grasp the correct cups following an order, move them under a coffee machine and move them to a tray.

Statistical analysis

For the Box and Blocks test a repeated measures ANOVA was conducted with Group as between-subjects factor and Test Moment as within-subjects factor. This was done after testing for normality with a Kolmogorov-Smirnoff test. For the Jar Lid and Zipper task of the SHAP we only analysed the post-test scores because many participants were unable to complete the task in the pre-test. After the missing values and outliers were removed the total number of included participants for the Jar Lid task was 17 (9 in SIM, 8 in VR) and for the Zipper 13 (7 in SIM, 6 in VR). With this limited number of participants the decision was made to test non-parametrically which was done with a Mann-Whitney U test. For the Cylinder test the normalized aperture was analysed using a linear mixed effect model with Group, Cylinder size and Test moment as fixed effects and individual participants as random effect. Interaction effects were also tested in this model.

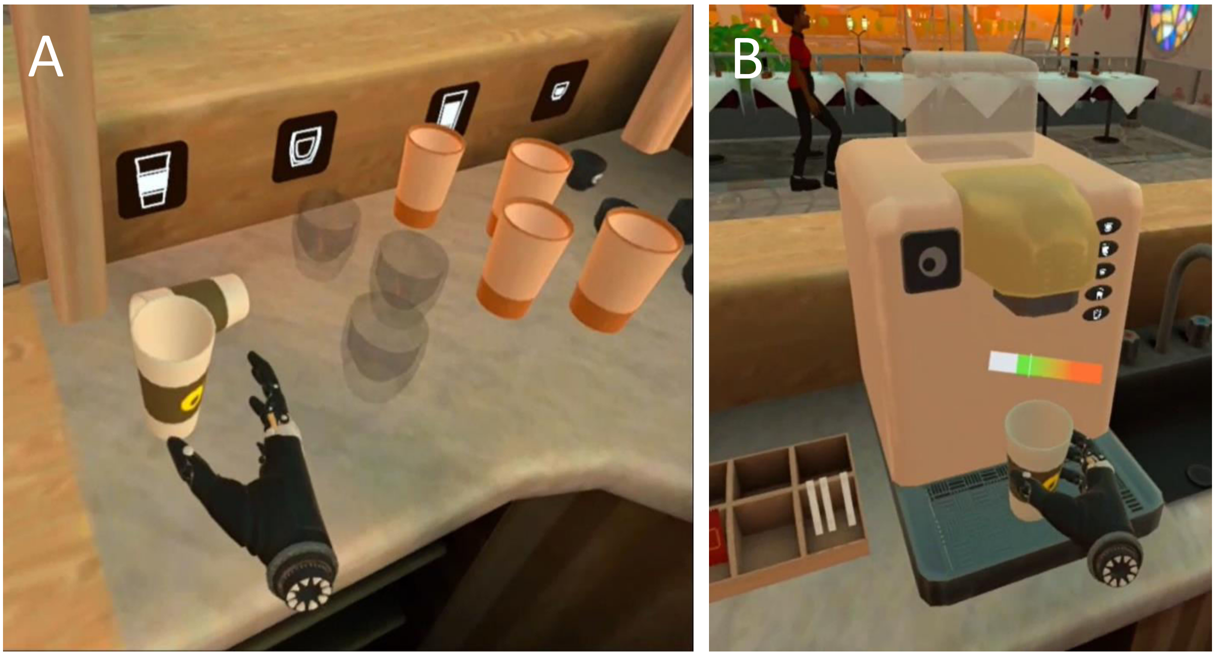

Figure 2. The virtual environment. A: The virtual prosthesis grabs a compressible cup (other cups can be seen on the right). Each cup had different properties, from left to right these were: the white cups were compressible, the transparent cups had glass cup properties and broke when grasped too hard, the brown cups were rigid and the black cups were small. B: The cup is placed underneath the coffee machine. The different coffee options are depicted on the right side of the machine by different buttons. The horizontal bar above the cup provides feedback on the grasping force. The colors of the bar indicate different ways the hand is interacting with the cup: white when the cup is not grasped, green when the cup is grasped and red if the cup is compressed or crushed.

RESULTS

A total of 20 participants were included, 8 males and 12 females with a mean age of 21.2 ±1.9 years. Ten participants were assigned to the VR group, 4 males and 6 females and ten participants were assigned to the SIM group, 4 males and 6 females.

For the Box and Blocks test a significant main effect of Test Moment was found, $F(1, 17) = 10.66$, $p = .005$. No significant effect for group or interaction effect was found. See figure 3A for the mean scores and standard error of the mean (SEM). Regarding the Jar Lid and Zipper tasks of the SHAP, a significant difference between groups was found for the Jar Lid task. The simulator group outperformed the VR group, $z = -2.5$, $p = 0.01$ (see figure 3B). The analysis on the aperture in the Cylinder test revealed a significant fixed effect of Test moment ($\chi^2(1) = 6.82$, $p = .009$) and of Cylinder size ($\chi^2(2) = 126$, $p < .001$), see figure 3C and 3D respectively.

DISCUSSION AND CONCLUSION

The main finding of this study is that the improvement of participants in the VR group was not different from the improvement of the participants in the SIM group in most tests. Therefore, it seems like both training methods are both effective in improving functional prosthesis control.

This is a relevant finding due to the fact that the VR group had to transfer the skills they learned in a virtual environment to actual use with a prosthesis simulator. Additionally, the VR group improved functionality at a similar rate with the SIM group, who trained with the prosthesis simulator and had thus an advantage.

The only test in the current study that does not support the equivalence claim between VR and SIM, is the result of the Jar Lid task of the SHAP where the SIM group outperformed the VR group in the post-test. Further research is necessary to explain this deviating finding.

One point that should be made is that VR training presents a number of advantages compared to the SIM group that are not analyzed in the current paper. Factors such as motivation, effects of individualized feedback and less fatigue due to the missing weight of the simulator could have a major impact on training effectiveness.

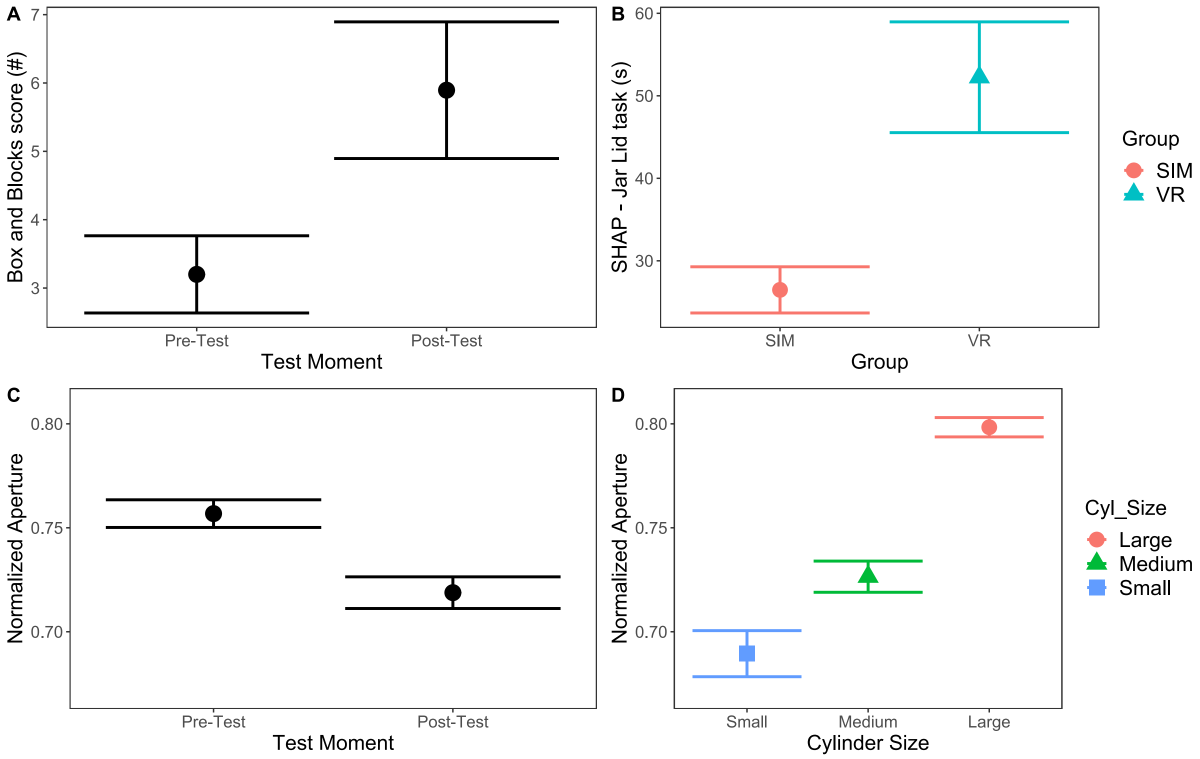

Figure 3. A) The scores Box and Blocks test for the Pre-Test and the Post-Test. The mean and SEM are presented. B) The completion time for the Jar Lid task from the SHAP for the VR group and the SIM group. The mean time and SEM are presented C) The normalized aperture of the Cylinder test for the Pre-Test and the Post-Test. The mean and SEM of the normalized aperture are presented. D) The normalized aperture of each individual cylinder size, Small, Medium and Large. The mean and SEM of the normalized aperture are presented.

To conclude, there seem to be no major differences between training in a virtual reality environment and training with an actual prosthesis simulator based on our results. That is why our conclusion is that there is no difference in improvement on effectivity between virtual reality and prosthesis simulator training. However, the current study used able-bodied individuals which is why future research should expand on the current design by including patients and also explore the motivational aspects of training with VR.

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