Exploring the Feasibility of EMG Based Interaction for Assessing Cognitive Capacity in Virtual Reality

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***Abstract*— With the growth and aging of the world population, the prevalence of cognitive diseases and disabilities like dementia and mild cognitive impairments increases. To determine the influence of such diseases, find therapeutic effects and further improve quality of life, cognitive assessment and training is required. This can be done with the application of high immersive technologies like virtual reality.**

In this paper we evaluate the feasibility of an electromyography (EMG) arm muscle-motion based interaction technique for controlling a VR cognitive performance diagnostic and training environment. Therefore, we compared the state-of-the-art controller input to our EMG based approach in terms of presence and user experience.

Results show significant differences in terms of Novelty and Dependability. Since there are only few significant differences regarding presence and user experience, the advantage of applying a more demanding physical motion interaction approach (EMG), seems to be a promising method with the potential of having a positive effect on the cognitive training progress. This is mainly caused by the fact that the implemented gesture interaction reinforces the connection between decision making and action execution.

I. Introduction

A recent study has shown that the peak performance of a human brain is reached between the age of 16 and 25 years. After this period, cognitive abilities like attention, spatial awareness or speed of information processing tend to decline [1]. To influence this natural change, specific training of such skills can help to increase performance and hence positively affect daily life. Willis et al. were able to show that by training cognitive skills, individuals become more effective in performing everyday tasks with varying complexity [2]. Additionally, Schmiedek et al. could show in a study that this does not only apply to teenagers or young adults, but to all age groups [3].

Apart from that, other research groups conducted studies indicating that brain training can also be beneficial in case of cognitive impairments, such as for the early phase of dementia [4]. There are several studies that support cognitive training as a potentially efficient method to postpone cognitive decline in patients with mild cognitive impairments (MCI). The research of Belleville is one example that reports a significant effect of cognitive skill training on MCI in terms of increasing memory performance [5].

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Since, according to the WHO, the world population is growing and aging rapidly [6], it is expected that by the year of 2030, more people aged 60 or older will live than children under 10 (1.42 vs. 1.35 billion). With this aging of society, cognitive diseases and disabilities like dementia and MCI will likely increase in the future as well.

To reduce the influence of such diseases and further improve quality of life, new tools for cognitive diagnostic and training need to be developed and existing tools need to be improved. With the use of technology, it is not only possible to easily reproduce and standardize test and training procedures, but also enables a high accessibility.

Although several already available digital tools train cognitive performance [7], [8], they show potential of improvement in at least one of the two following aspects.

First, some research suggests a combination of physical and psychological exercises to reinforce effects on cognitive performance development [9], [10]. Significant training effects were found in the group exposed to the combined cognitive and physical training compared to the control groups that only experienced a single or no intervention in a five years study conducted by Wolf et al. [11].

Second, the immersion and engaging (user experience) of the technology in use plays a key role since it amplifies internalizing learned techniques and approaches which enables a reinforced transfer to daily life [12], [13]. Immersion originates when users are surrounded by a virtual world that includes them and provides them continuously with stimuli and experiences, which results in a certain level of presence. Presence is the feeling of being part of such a virtual environment. If the feeling of presence is high, being in the virtual environment feels like visiting a real place [14, pp. 45].

Within its third hype cycle, Virtual Reality and with it head-mounted displays seem to influence a broad variety of application areas by creating a higher immersion compared to other mediums, such as mobile or desktop experiences. The advantage of this high immersion is applied in different medical fields. It is used in exposure therapies where VR allows patients to have the impression of being exposed to something that induces fear or stress while being in a save environment [15], [16]. Furthermore, VR is applied for pain treatment where virtual environments are used to distract patients from their pain [17]. In both cases, high immersion and feeling of presence are crucial for the effectiveness.

Since we identified this lack of applying VR in combination with physical motion to diagnose and train cognitive

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performance, we developed a virtual training environment. The proposed interaction scheme consists of two different gestures based on EMG signals of the forearm. The aim of this paper is to explore the feasibility of this approach. Therefore, we compare our EMG-based approach to the state-of-the-art controller input regarding presence and user experience.

II. METHODS

A. Virtual Environment

The purpose of the developed virtual environment is to train and assess cognitive skills related to visual and spatial awareness as well as executive functions, such as selective attention, spatial perception, scanning and cognitive flexibility. In addition to the previously named advantages, virtual reality creates a fully explorable, 360° space as well as depth perception through stereoscopic vision. This awareness of oneself and other objects in the room, and their relation to each other also has a significant influence on the action decisions [18]. To combine these arguments in a system, we designed an application in which the user has to differentiate between stimuli, visualized as spheres that differ in color and moving direction. All stimuli move hovering over the ground. Depending on the combination of color and moving direction, a stimulus is destroyable by a specific trigger or not. In case the stimulus is of blue color and moves towards the user, or is purple and moves away from the user, it is destroyable by the user's action. All stimuli are spawned randomly on a circle around the player. The spheres move on a straight line towards or away from the user. To analyze the user's performance, all actions in the virtual environment, such as destruction of objects, object lifetime, or user error rate, are logged. To encourage users during the game, a score is displayed which is raised or reduced depending on correct or wrong user actions.

To meet the individual training conditions of each user, the game becomes more complex in case 70 % of all stimuli are destroyed within 10 seconds of their spawn-time by decreasing the interval at which objects spawn, increasing the maximal allowed number of objects as well as their maximal speed. In contrast, a decrease of complexity occurs when less than 50 % of the spawned objects are destroyed within their lifetime. To display the developed virtual environment to the participants the HTC Vive [1] system was used.

B. Input Modalities

We implemented two different interaction modalities for our virtual environment. One is the EMG based gesture control by using the Myo armband (Thalmic Labs Inc., Kitchener, Canada). The armband consists of an accelerometer and eight EMG sensors that measure the activity of the lower arm muscles. The two gestures used as input techniques for the developed application are spreading of the fingers and clenching them into a fist. The Myo SDK[2] was used to process the signal and recognize the gestures. A fist gesture was chosen to interact with destroyable objects moving towards the player. Vice versa, objects moving away from the user were eliminated when using a finger-spread gesture.

For the controller based interaction the HTC Vive Controller was used. Participants were able to eliminate destroyable objects moving towards them by pushing the "trackpad" with their thumb and destroyable objects moving away by using the "trigger button" with the index finger.

Since only objects in focus should be destroyable, a stimulus was selected by choosing the object closest to the middle of the field of view. The selected object was visually highlighted.

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

[2] https://developer.thalmic.com/

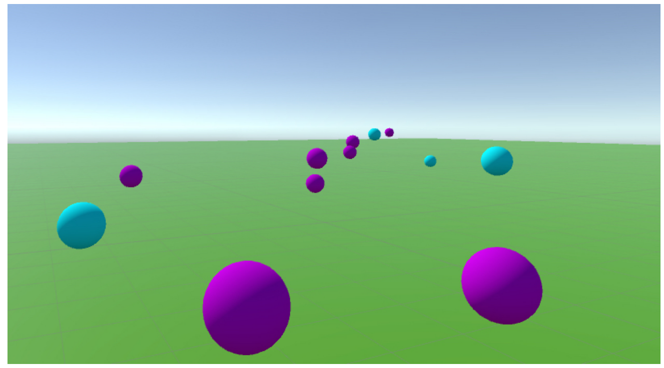

Fig. 1. Virtual environment showing the different kind of spheres. Users can destroy the spheres using EMG or regular controller interaction. The spheres move towards or away from the user in a straight line.

C. User Experience and Presence

For measuring presence and user experience depending on the interaction concept, we used the Presence Questionnaire (PQ) and the User Experience Questionnaire (UEQ), respectively.

The PQ uses a seven-point scale that includes semantic differentials to measure how much presence a person experienced in a virtual environment and which aspects of the environment might have had an influence on that experience. Specifically, it touches base on involvement and immersion of the user in the virtual environment. This splits up in the three subcategories *involved/control*, *natural* and *interface quality* [19].

The UEQ investigates six aspects to the user experience: *Attractiveness*, *Perspicuity*, *Efficiency*, *Dependability*, *Stimulation* and *Novelty*. Whereas Attractiveness describes the general like or dislike of a user, Perspicuity describes how easy it is to understand and learn the use of an application. To what degree users feel in control while using the product is reflected through Dependability. While these aspects build the pragmatic quality of the product, Stimulation and Novelty represent the hedonic quality of the user interface to be evaluated. The value of each aspect can be shown on a scale from -3 to 3 whereas 3 indicates a very good user experience. Results between -0.8 and 0.8 are considered as neutral evaluations [20].

D. Participants

In the study a total of 18 volunteers took part. They had an average age of 22±4 years (M ± SD). All of the participants were physically active at least once a week. The requirements for participation were the ability to see colors, being able to use a head mounted display and to perform light athletic activity.

E. Experimental Design

Being able to compare the two input modalities in terms of presence and user experience, we used a within-subject design. Therefore, every participant experienced both conditions (interaction techniques) while completing a task. The task consisted of using the application for one minute and trying to score as many points as possible. To avoid influences of fatigue or learning effects a counterbalanced measures design was chosen by using a Latin-Square order [21].

F. Procedure

At first, demographic data and information regarding the activity level of the participants were acquired. In case the participant started with the EMG-based interaction first, an introduction on how to correctly wear and perform gestures with the myo armband was given. It was ensured that participants were able to perform each gesture and switch between the two gestures. Independently of the first chosen input device, each participant had the chance to understand the basic game mechanism by experiencing a short trial period of 30 seconds. After each condition, participants were asked to fill out the PQ and UEQ. In a final step, the participants' reflective thoughts were gathered through a recorded semi-guided interview.

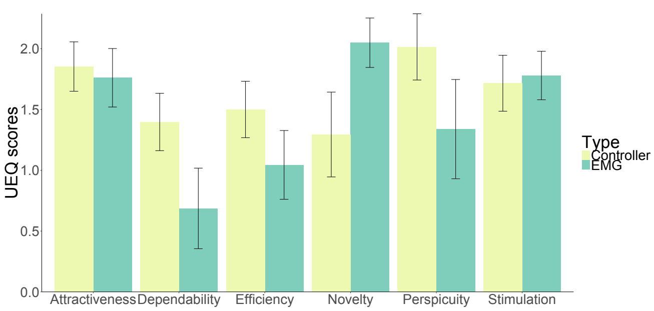

Fig. 2. The bar chart diagram shows a comparison of controller and EMG based interaction regarding the user experience. Pragmatic (perspicuity, efficiency and dependability) and hedonic (stimulation and novelty) quality was examined as well as attractiveness.

III. Results

The evaluation was separated into the different study sections *user experience*, *presence* and *feedback of the semi-guided interview*. 17 out of 18 participants completed the whole study procedure. One participant was not able to finish the study due to motion sickness.

A. User Experience

Figure 2. shows a comparison between Controller and EMG interaction in regard to the different aspects of the UEQ. Controller interactions have better results in terms of the pragmatic parameters perspicuity, efficiency and dependability by 0.8, 0.46 and 0.7 points, respectively, compared to the other approach. Regarding the hedonic parameters novelty (2.05) and stimulation (1.78), the muscle-motion based interaction was experienced more valuable by the participants. With a value of 1.85 controller interaction achieved better results in terms of attractiveness compared to EMG interaction (1.76).

A paired-samples t-test with an significance level of 0.05 was conducted to compare the two different interaction concepts. A significant difference was found for dependability (p=0.023) and novelty (p=0.016).

B. Presence

Results of the PQ offer an insight into how present the participants felt in the virtual reality experience created by the application. A conducted paired-samples t-test with an significance of 0.05 showed no significant differences among the two conditions. The results of the PQ coincide to a certain extend with those of the UEQ (see Table I). Whereas the aspects *Realism*, *Quality of interface*, *Possibility to Examine* and *Self-Evaluation of Performance* tend to show just minor differences, the *Possibility to Act* parameter has a difference of 19 % and thus seems to be experienced differently for the two conditions among the participants.

TABLE I

Results of the Presence Questionnaire

Mean (± standard deviation) values for the interaction types and the five scales of the PQ. Real = Realism, Poss = Possibility to Act, Qual = Quality of Interface, Exam = Possibility to Examine, Selfev = Self-evaluation of Performance.

	PQ Categories				
	Real	Poss	Qual	Exam	Selfev
Controller	33.88 (±6.29)	23.18 (±2.94)	14.94 (±1.78)	14.06 (±2.7)	12.06 (±1.67)
EMG	32.94 (±6.61)	19 (±3.44)	13.41 (±2.45)	13.71 (±2.49)	11.24 (±2.16)

C. Interview Feedback

The semi-guided interview, conducted after completing all tasks with both input methods, showed different opinions of the participants about their experience using the application. The majority of the participants (16) stated, that using the EMG-based interaction is more interesting and exciting than using controller input. Furthermore, they found gesture control to be more intuitive to eliminate stimuli.

However, all participants stated that the controller interaction worked more dependably and hence was easier to use. 12 out of 17 participants found that using the EMG-based approach required to think more about actions and therefore was experienced as being more stressful. Two participants argued that it was more difficult to see in which direction an object was moving when it was far away.

IV. Discussion & Conclusion

In this paper we examined an alternative EMG-based input modality for a VR cognitive training environment. Therefore we used the low cost myo armband, which provides a high wearability and hence enables an easy user control. This approach was compared against a state-of-the-art controller interaction in terms of presence and user experience.

Results show the EMG-based interaction has advantages in its hedonic qualities. Although the interaction is comparable in terms of stimulation, there is a significant effect in its novelty. This means that the EMG-based interaction approach is experienced as new in the context of medical assessment and training tools and shows the potential of improvement and further investigations into this direction.

In terms of presence there are no significant differences among the two tested interaction methods, meaning that the EMG-based method does not affect the immersion of the user. However, since it does provide a more complex interaction for the user and hence is a more cognitively demanding task, it is a promising approach to have a positive effect on the progress of training. Therefore, we would recommend to chose the EMG interaction method in the context of VR cognitive training over current state-of-the-art controller interactions.

Nonetheless, the conducted study also identified weaknesses of the system. In terms of pragmatic quality (i.e. dependability, perspicuity) there are still deficits that result from two main aspects. Firstly, the system is not able to detect every interaction, due to the complexity and susceptibility for errors of the involved signal processing and classification. Secondly, the individual experience of the user that gesture interaction is a more demanding task than using a default controller. This is emphasized by the results from the presence questionnaire, which shows a major difference among the interactions in the possibility to act. Also qualitative data from the semi-structured interview indicates that participants in some cases had difficulties to interact with the system when the EMG-based interaction was applied. To address this problem we will investigate the accuracy of the system in upcoming work and try to improve the gesture recognition.

However, the developed EMG-based interaction method was designed as an alternative input modality for our cognitive assessment and training virtual reality environment. Since the myo armband as device itself is easy to use and shows a high level of wearability, we argue that using it, and with it gesture interaction, is a feasible alternative approach for interacting in the developed virtual environment. Additionally, this kind of interaction promises to have a positive effect on the user's training progress. Our future work will investigate this effect and improve the system's gesture detection accuracy.

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