The effect of golf putting practice in virtual reality on cortical activation and real-life putting performance

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Abstract

Research for the use of virtual reality (VR) in training has in the recent years been a hot topic, with new VR equipment being developed each year. In this experimental study, the aim was to examine whether VR training would alter cortical activity and transfer learning from VR to real life performance.

METHODS: Novice golf players were divided into a VR training group (TG) (n=9) and a control group (CG) (n=9). Both groups performed a test and retest with 10-14 days between tests. The tests consisted of 50 golf putts on artificial grass while wearing an electroencephalography (EEG) system. Between tests, TG performed three training sessions of 180 putts in a VR golf application with a minimum of 1 day rest between each training session. The main outcome of the tests was radial error (cm) and EEG frequency power, along with balls holed during training.

RESULTS: No difference was found after the intervention in the cortical activity at any frequency band between TG and CG. However, a significant increase in performance radial error was seen between TG and CG after the intervention ($p = 0.001$), along with a significant increase in putts holed in VR between every training session ($p < 0.05$)

CONCLUSION: The present study concludes that VR can be used to increase real life performance for novice golfers, but not alter the cortical activation. A more comprehensive study will have to be conducted to investigate whether cortical changes will occur when VR performance hits a plateau.

Keywords: Virtual reality, electroencephalography, golf putting, skill training

1 | Introduction

Virtual reality (VR) is a sophisticated system that uses advanced technology and computer graphics to create a realistic virtual environment (Neumann *et al.*, 2018). In an virtual environment, it is possible to create a world that provides a sensory experience via the built-in tracking of motion (input) and an optimized LCD screen (output), which together can provide a sense of a realistic world, and open an entirely new avenue for training one's skills (Burdea and Coiffet, 2003; Craig, 2013).

The realistic reproduction of reality has resulted in VR being used in areas such as medicine (Grantcharov *et al.*, 2004; Al-Saud *et al.*, 2017; Frederiksen *et al.*, 2019), rehabilitation (Faria *et al.*, 2018; Park, Jung and Lee, 2020) and sports (Tirp *et al.*, 2015; Neumann *et al.*, 2018; Farley, Spencer and Baudinet, 2020), where the technology is mostly used in areas where training in the real world is difficult to organize due to external factors, is dangerous or impractical (Jerald, 2015). An example of this is a study by Seymor et al., 2002, where they tested whether practicing a gallbladder surgery in VR, could improve the same procedure in reality. Their results showed that the training group made significantly fewer errors than the control group, during actual surgery (Seymour *et al.*, 2002). Another area in which VR is often used is in the training of airline pilots. Here, a study of Hays et al. 1992 investigated the effect of using VR simulations as part of pilot training, to which they found using a simulator combined with ordinary flight was to be preferred, compared to exclusively ordinary flight (Hays *et al.*, 1992).

Looking at the literature on the use of VR in sports situations, most studies on training in virtual environments are aimed at endurance training, and mostly performed using large systems that take up a lot of space, where studies on skill-based sports using smaller and more accessible systems are rare (Lee, Chung and Lee, 2013; Neumann *et al.*, 2018; Akbaş *et al.*, 2019). One of the studies on skill-based sports is by Petri et al., (2019), and examines the use of VR in karate training. In this study, they found significant improvements in sport-specific parameters in the group that trained karate in VR (Petri *et al.*, 2019). These findings are extended in a study by Michalski et al., (2019), which examined the effect of practicing table tennis against computer-controlled opponents in VR. The study revealed that subjects training table tennis in VR had improved significantly compared to the control group (Michalski *et al.*, 2019). In addition, a study by Harris (2020) also examined whether a single practice of golf putting in VR could result in the same improvement in performance as a real practice of golf putting. They found similar improvement in both groups, suggesting that it might be used as a supplement to real life training (Harris *et al.*, 2020).

Problems can however arise when using VR as a training method. These problems stem from the formation of a virtual environment in the VR headset, trying to resemble reality, but no one has of yet succeeded in creating something that looks and feels 100% like reality. This has the risk of creating problems, as it is not possible to generate the same haptic, tactile and visual feedback as in reality (Düking, Holmberg and Sperlich, 2018). This is mainly due to the virtual environment, which rarely creates a 1:1 visual depth, and therefore potentially distorts the transfer of the learned motor skill (Kramida, 2016; Harris *et al.*, 2019). However, the general question still lies in the effectiveness of learning and transferring skills from VR to the real world (Neumann *et al.*, 2018).

When it comes to learning new skills, transferability between sports is considered a classic theme, where Thorndike in 1914 already came up with a suggestion, that by creating situations similar to those in reality, a good transferability could be obtained (Thorndike, 1914). This theory has since been further developed in sports by

Baker and Côte (2006), who found several different elements that were transferable from one sport to another; 1. The physical form, which relates to the physiological changes, such as cardiorespiratory changes; 2., Movement, which relates to the anatomical and biomechanical similarities between tasks; 3., Perceptual elements, which relate to capturing information about the environment; and 4., Conceptual elements, which relate to being able to recognize similarities in strategies and rules (Baker and Côte, 2006).

In the literature on learning and improving one's motor skills, it is shown how it is the human brain and its ability to reorganize, that enables us to improve in relation to the challenges that are posed (Karni *et al.*, 1998; Censor, Sagi and Cohen, 2012). One of the adaptations seen through training is called the psychomotor efficiency hypothesis. This hypothesis describes how improvements in the cognitive motor process involve a refined set of inputs, as well as how poor performance is associated with non-essential neural activation (Hatfield and Hillman, 2001; Hatfield *et al.*, 2004; Rietschel *et al.*, 2012). The neural efficiency is often examined using electroencephalography systems (EEG), that uses electrodes to record the postsynaptic potentials in the pyramidal neurons of the cerebral cortex (Nunez and Srinivasan, 2005). The potentials of the neurons generate oscillations at different frequencies which are often utilized in studies, where it has been shown that experts in golf, archery, and rifle shooting have regions with lower cortical activation than those of novices (Hatfield *et al.*, 2004; Baumeister *et al.*, 2008; Cooke *et al.*, 2014; Wang *et al.*, 2020).

Few studies have examined whether a training intervention has a similar effect on cortical activation. One of them is Landers et al., (1994), who showed that by training archery for 15 weeks, an improvement in performance of 62% is seen, as well as alpha synchrony of the left side temporal (T3) cortical activation, prior to the shot (Landers *et al.*, 1994). These results are extended by Kerick et al., (2004), who studied shooting training at the United States Naval Academy. Through their training, all soldiers showed an increased shooting performance, while also showing an improved synchronization of alpha power in the left temporal area (Kerick, Douglass and Hatfield, 2004). Some of the same results are shown in golf putting studies, where only three training sessions of golf putting showed an improved performance, as well as an regional decrease in alpha power at the frontal part of the brain (Gallicchio, Cooke and Ring, 2017). Adding to this, similar findings are found in a study by Zhu (2011), also examining golf putting, for which they found a significant improvement in performance, as well as a lower alpha frequency coherence between the frontal midline region (Fz) and the left temporal (F3) part of the brain (Zhu *et al.*, 2011).

It is general for all the studies above that there is some transferability between VR and real-life performance and that real life training alters the cortical activity. Based on this, the present study aims to investigate whether similar changes to cortical activation is seen through training golf putting in VR. It was hypothesized that VR training would alter the cortical activation and improve real-life putting performance.

2 | Methods

2.1 | Participants

Twenty individuals (14 male, mean age 26.3 years, SD = 2,3, mean height 180,33 cm, SD = 9,9, mean weight 82,5 kg, SD = 13,1) were recruited using written forms. All participants were provided details of the study before attending testing and were instructed to carefully read through the exclusion criteria. For the participant to take part in the study, they were obligated to fulfill the criteria of being a novice golfer. In this study, a novice golfer was characterized as a person having no EGA score or prior formal experience with the sport (Cooke *et al.*, 2010). All participants were provided with the details of the study before attending testing and gave written consent before the testing began. Ethical approvals were obtained from The Science Ethics Committee for the North Jutland Region prior to data collection.

2.2 | Design

A repeated measure design was used (pre-test and post-test) with a between-subject variable. Outcome measures were putting accuracy along with EEG frequency power.

2.3 | Procedure

All participants were randomized into either a control (CG) or training group (TG), using a randomization script. CG attended the lab for two test sessions of approximately 60 minutes each session. TG attended the lab for five sessions, two test sessions of approximately 60 minutes and three training sessions of 30 minutes. All participants performed the pre and posttest with 10-14 days in between each test. On average, the test-retest interval was 12 (SD = 1.58) days for TG and 12,11 (SD = 1.45) days for CG, with no significant difference between groups ($p > 0,05$). For TG, the average interval from last training session to retest was 2.44 (SD = 1.01) days. The tests consisted of 50 putts on the putting green, while wearing an EEG system to record brain activity. The EEG recordings were started just before the first shot and continuously recorded until all 50 shots were completed, which took approx. 10-15 minutes. The decision of 50 test putts was based on inspiration from previous studies as well as the ambition of securing enough EEG data to do an analysis, even if some trials would be corrupted (Cohen, 2014; Gallicchio, Cooke and Ring, 2017). Between the two tests, the training group performed three training sessions in VR, each consisting of 180 putts, which was chosen with inspiration from real-world golf studies with increased performance outcome (Zhu *et al.*, 2011; Gallicchio, Cooke and Ring, 2017). During VR training, the participants' performance was assessed by counting the number of holed putts. As between session learning is an important part of improving motor skills, all participants in the training group were instructed to have at least one day between each session (Kami *et al.*, 1995; Censor, Dimyan and Cohen, 2010; Censor, Sagi and Cohen, 2012).

2.4 | Tasks and materials

2.4.1 | Real-life golf putting

Real-life golf putting took place indoor on a 4-meter-long artificial green. The ball was positioned with 2.4 meters to the target hole of diameter 10.80 cm (official hole size) (fig. 1, B). To correspond with the simulation in VR, the hole was visible with a small drop and a 1 cm back stopper, assuring that the ball would remain in place, if putted with the correct force. During test performance, participants were not given verbal feedback on the radial error, but they were able to see the landing spot of the ball, providing some feedback on all trials. All participants used the same Vantage true line series golf putter (432 gram) and a standard size (4.27 cm) golf ball.

2.4.2 | VR golf putting

The VR golf putting were performed in the golf simulation application Topgolf, developed by Golf Scope Inc. (Golf Scope, 2020). The simulation was conducted through an Oculus Quest 2 headset with 128 GB storage space and weighing 571 grams (Facebook Technologies LLC, 2021). The Oculus Quest headset is wireless and displays the picture on a fast-switch LCD panel with a 1832x1920 per eye resolution and a refresh rate of 72 Hz, giving the participants a 360-degree environment with a 110° field of view (fig. 1, D).

Additionally, a custom handle was created to fit the Oculus controller (308 gram), giving the participant the same grip as in real life (fig. 1, C).

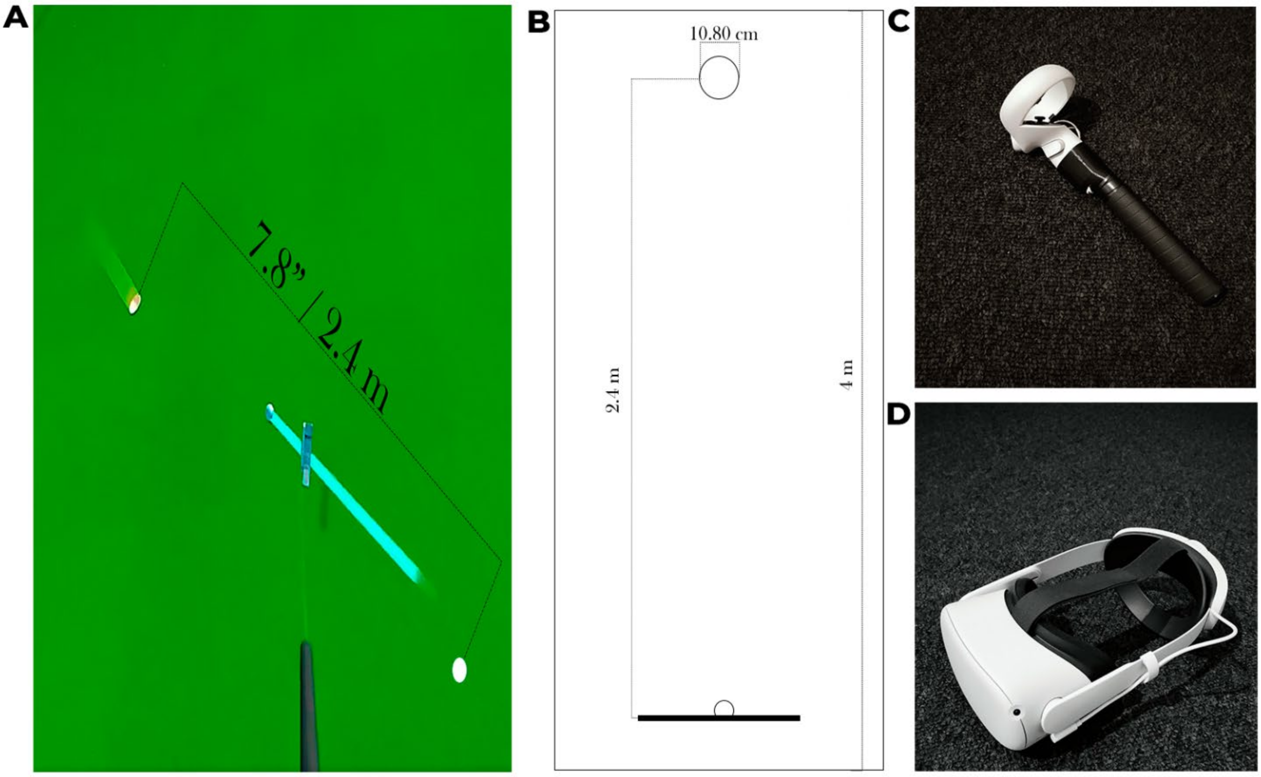

FIGURE 1 **A.** VR training environment used in VR training with in-game measurements of 7.8 feet/2.4 meters. **B.** Real-life measures of the artificial golf course used in tests. **C.** VR controller with golfing add-on simulating the grip of a golf club. **D.** Oculus quest VR headset used in the experiment.

During VR training, the environment provided auditory feedback, mimicking the sound of a real golf club hitting the ball, along with small vibrations from the controller. To create a VR environment as close to the real-world environment as possible, the applications practice tool was used, making it possible to set up a course with the same 2.4 meters from the placement of the ball to the hole (fig. 1, A). The simulation provided an ambient environment throughout the entire training, which has been shown to provide an immersive experience (Harris *et al.*, 2019).

2.4.3 | EEG recordings

During the real-life putting test and retest, participants brain activity was assessed by a 32 active electrode LiveAmp EEG cap (BrainVision, Morrisville USA), which used the 10-20 system, at FP1, FP2, AFz, F3, Fz, F4, FC5, FC3, FC1, FCz, FC2, FC4, FC5, C5, C3, C1, Cz, C2, C4, C6, CP5, CP3, CP1, CPz, CP2, CP4, CP6, P3, Pz, P4, PO3, PO4, with a ground electrode placed on the forehead, and a reference electrode placed on the mastoid, just behind the left ear (Abhang, Gawali and Mehrotra, 2016). Before applying the EEG cap, the center of the participants head was found using a tape measure from which the cap was placed (Acharya *et al.*, 2016). As the EEG cap was placed on the head, a high-viscosity electrolyte-gel (EasyCap, 2021) was applied to each electrode using a plastic syringe. To ensure good connection between electrodes and the scalp, the visual interface of the software Brain Vision recorder (BrainVision, 2021) was used to insure that each electrode had an impedance level lower than 25Ω (Kappenman and Luck, 2010). The EEG system was wireless, and all recorded brain activity was sent through an amplifier with a sampling frequency of 512 Hz, transforming the signal to a digital signal to be captured using a laptop running Brain Vision recorder.

2.4.4 | *Performance measures*

Putting performance in real-world putting was assessed using radial error (cm) of the ball to the hole as it is often used in golfing studies (Wannebo and Reeve, 1984; Shafizadeh, McMorris and Sproule, 2011; Causer *et al.*, 2017). The radial error was measured from the boundary of the hole to the middle of the ball using a tape measure after each attempt. If the ball landed in the hole, "zero" was noted, and if the ball rolled out of the green, the distance from the hole to the back of the artificial green was noted (110 cm).

2.5 | Preparing EEG data

2.5.1 | *Locating the golf swing*

Before analysis of the EEG data, the data had to be segmented to define when the golf swing happened. The EEG cap had a built-in accelerometer located on the back of the head, tracking the head movement. Using Matlab (Mathworks, 2021) and the accelerometer data, it was possible to examine the movement of every subject. To do so, the data for the x, y and z-axis was extracted and filtered using a lowpass Butterworth filter design with a normalized cutoff frequency at 0.75Hz (Butterworth, 1930). Afterwards, the acceleration was differentiated and plotted on a chart (fig. 2). The reason for doing this was due to a common trend of subjects looking at the ball while preparing for the shot and then turning the head when initiating the shot. This movement is seen in figure 2, where all the peaks are indications of large head movements, and presumably an indication of a golf putt. To analyze if this was correct, the highest peak of movement was used as a reference and a threshold was set to capture all movement above. All subject data was then manually analyzed from the plots, to make sure the peaks of the movement matched the amount of 50 shots, and no noise was interrupting the clear indication of a shot. If the plot didn't show a clear indication, the script was adjusted by changing the threshold and/or movement axis. As seen in figure 2, the script was not always able to define all 50 putts without getting into trouble with other movement. This resulted in an average of 46.79 trails per subject (SD = 2,73).

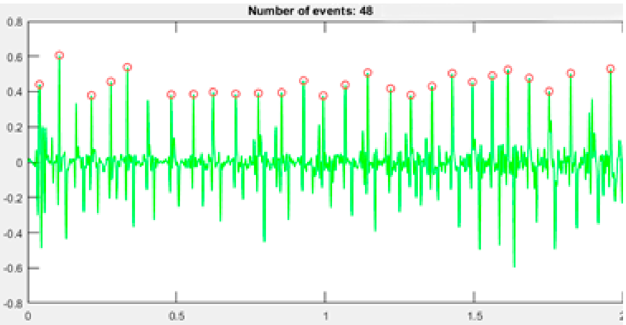

FIGURE 2 Shows the differentiated acceleration and the script localizing golf putts for a single test of a subject, using movement on the x-axis and a threshold of 60%. Red circles indicate a golf putt.

2.5.2 | *Processing EEG data*

The software Matlab (Mathworks, 2021) with the EEGLAB plugin (Delorme and Makeig, 2004) was used to prepare the data for analysis. The preparation methods used on the data are as following: The raw EEG data were first run through a low and high pass filter, removing everything below 1 HZ as it is seen as default activity of cortical circuits (Sanchez-Vives, Massimini and Mattia, 2017) and above 48 Hz, as frequencies of 50 Hz is seen as powerline noise (Sörnmo and Laguna, 2005). To further clean the data, an independent component analysis (ICA) was applied (Jung *et al.*, 2000; Delorme and Makeig, 2004; Urigüen and Garcia-Zapirain, 2015). As the ICA was run on the data, it was able to identify all the different components in the signal and suggest removal of signal containing eyeblinks and noisy electrodes. All components were manually checked and either accepted or rejected, depending on the behavior of the signal (Jung *et al.*, 2000). After filtering and cleaning the data, it was divided into epochs of interest, where before and after the golf putt, was chosen as the interesting moments (Gallicchio, Cooke and Ring, 2017). To examine this, the time from -2s before to 1s after the initiation was chosen. This timespan was then separated into two segments: one segment before the putt (BFH), and one after (AFH). The BFH segment was created between -2000ms and -250ms before the initiation of the golf put. The AFH segment was created between the initiation of the golf putt to 1000ms after. For both segments, a baseline reference was created at -4000ms to -3000ms before initiation, which were subtracted from the chosen segments (Cohen, 2014). To find the frequency power for all frequencies, a Fast Fourier Transform (FFT) algorithm was applied to every set of data (Rao, 2011; Cohen, 2014). After filtering, cleaning, and applying FFT to all of the channels, the average power for Delta (1-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), Beta (13-30 Hz) and gamma (>30 Hz) at both BFH and AFH was printed for every subject at all electrodes, and gathered in a document for further statistical analysis (Ivanitsky *et al.*, 2009).

2.6 | Statistical analysis

Data were analyzed using SPSS software package version 27 (SPSS, Chicago, Illinois, USA). The primary outcome measure was difference in radial error performance, number of balls holed during VR training, and frequency power between pre- and posttest. All data was tested for normality using Shapiro-Wilks's test, which showed no normally distributed data for both pre- and posttest putting performance (P < 0.01) and EEG data (P < 0.01). For VR training, the data was normally distributed, however, due to a low number of subjects, nonparametric test were adopted for analysis. Putting performance from test to retest in groups were analyzed using Wilcoxon signed ranks test and the difference between groups were examined by a Mann Whitney U test. Number of balls holed in VR training were examined by an analysis of variance (Friedman test). The EEG data was analyzed in groups using Wilcoxon signed-rank test and between groups using Mann Whitney U test. To further analyze changes in brain activity, all electrodes were placed into brain areas of interest (AOI): Frontal (FP1, FP2, AFz, F3, Fz, F4), Left temporal (FC5, C5, CP5), left central (FC3, FC1, C3, C1, CP3, CP1), midline (FCz, CZ, CPz), Right Central (FC2, FC4, C4, CP2, CP4), right temporal (Fc6, C6, CP6) and Occipital (P3, Pz, P4, PO3, PO4). All electrodes in an AOI were then averaged and tested for differences using a Mann Whitney U test.

3 | Results

3.1 | Real life putting performance

Analysis included 18 of 20 subjects (nine in each group). No difference in pretest radial error performance was found between TG and CG (P = 0,197) whereas after the training intervention, TG improved real life putting performance significantly compared to both pretest (P < 0,01) and CG (P = 0.001) (fig. 3). However, one subject in TG differentiated from the group but with no critical effect on the overall level of significance (appendix 1).

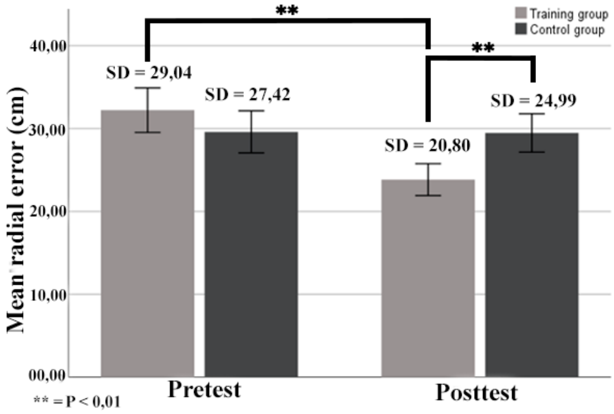

FIGURE 3 Mean radial error scores for both groups between pre- and posttest. Significant differences were found in the training group between pre- and posttest. No significant difference was found between pre- and posttest in the control group.

3.2 | VR Training performance

TG improved VR putting performance significantly between every training session (P < 0.05). This it seen in figure 4 where TG experienced an increase of 40,45% from training 1 to training 2, and 26.14% between training 2 and training 3. This adds up to an overall performance improvement of 77.17% from training 1 to training 3.

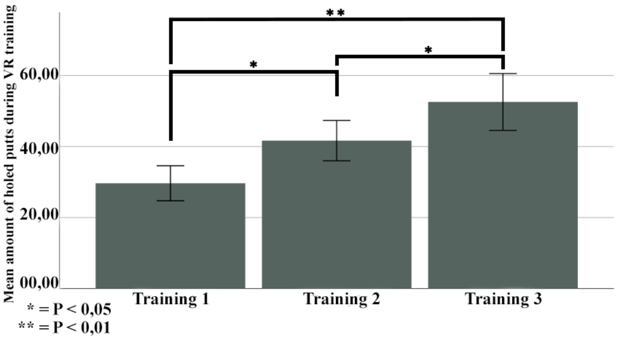

FIGURE 4 Average number of holed putts for each training session. Significant improvements were found between every training session.

3.3 | EEG data

A Mann Whitney U test was conducted on the average power of all electrodes combined for the Delta, Theta, Alpha, Beta and Gamma frequency bands. The test showed no significant differences

TABLE 1 Showing difference in average power and significance level between TG and CG at pre- and posttest, as well as for BFH and AFH.

Frequency	Time	Test	Average Power CG	Average Power TG	p-value
Delta	BFH	Pretest	3,56077E+14	4,04922E+14	0,072
Delta	AFH	Pretest	3,47079E+14	3,89567E+14	0,126
Delta	BFH	Posttest	3,54824E+14	3,72702E+14	0,601
Delta	AFH	Posttest	3,51276E+14	3,61167E+14	0,934
Theta	BFH	Pretest	4,17896E+14	3,94218E+14	0,548
Theta	AFH	Pretest	4,16325E+14	3,87739E+14	0,424
Theta	BFH	Posttest	4,1337E+14	4,32409E+14	0,283
Theta	AFH	Posttest	4,08409E+14	4,42172E+14	0,089
Alpha	BFH	Pretest	4,16941E+14	3,749E+14	0,084
Alpha	AFH	Pretest	4,09962E+14	3,80299E+14	0,254
Alpha	BFH	Posttest	4,14316E+14	4,00557E+14	0,707
Alpha	AFH	Posttest	4,16534E+14	3,84007E+14	0,200
Beta	BFH	Pretest	3,67305E+14	4,28006E+14	0,018*
Beta	AFH	Pretest	3,55729E+14	4,37296E+14	0,001*
Beta	BFH	Posttest	3,68217E+14	3,85156E+14	0,762
Beta	AFH	Posttest	3,62701E+14	4,37296E+14	0,323
Gamma	BFH	Pretest	4,58831E+14	3,84485E+14	0,115
Gamma	AFH	Pretest	4,37685E+14	3,97296E+14	0,161
Gamma	BFH	Posttest	4,28774E+14	4,03247E+14	0,276
Gamma	AFH	Posttest	4,37685E+14	3,97206E+14	0,310

* = p < 0.05

in the overall average power between CG and TG at any frequency band for both BFH and AFH after the intervention (P > 0.05) (table 1).

Even though there was no significant change after the intervention, a trend of TG having a lower Beta power after the training was observed, as TG having a significantly higher Beta power at pretest than CG (P < 0.05).

3.4 | Alpha power

As changes of cortical activity in other studies has been perceived as regional changes in alpha power, all AOIs were tested for differences in alpha power between TG and CG (Zhu *et al.*, 2011; Gallicchio, Cooke and Ring, 2017) (table 2).

TABLE 2 Showing average alpha power for TG and CG at all AOIs for both BFH and AFH. No significant changes were found between the two groups.

AOI	Time	CG average power posttest	TG average Power posttest	p-value
Frontal	BFH	4,42E+14	4,84E+14	0,393
Frontal	AFH	4,54E+14	4,53E+14	0,931
Left temporal	BFH	4,04E+14	4,45E+14	0,697
Left temporal	AFH	4,20E+14	4,59E+14	0,829
Left central	BFH	4,01E+14	3,52E+14	0,335
Left central	AFH	4,22E+14	3,58E+14	0,161
Midline	BFH	3,75E+14	3,26E+14	0,710
Midline	AFH	3,48E+14	3,19E+14	0,710
Right central	BFH	4,16E+14	3,48E+14	0,082
Right central	AFH	3,92E+14	3,34E+14	0,070
Right temporal	BFH	4,02E+14	5,20E+14	0,061
Right temporal	AFH	3,68E+14	4,62E+14	0,087
Occipital	BFH	4,06E+14	3,88E+14	0,690
Occipital	AFH	4,35E+14	3,57E+14	0,323

* = p < 0,05

As seen in table 2, no significant changes in alpha power between CG and TG were found in any of the examined AOIs (P > 0.05).

3.5 | Beta power

Looking closer at the trend of a change in Beta power for TG after the intervention, showed that TG had a significantly higher Beta power than CG in the pretest, at both BFH (p = 0.018) and AFH (P = 0.001), but no significant difference after the intervention at either BFH (P = 0.762) or AFH (P = 0.323), revealing a chance for a change in Beta power (fig. 5). But testing the Beta power from pre- to posttest, showed no significant changes in either BFH (p = 0.080) or

AFH (p = 0.113), suggesting no change in Beta power.

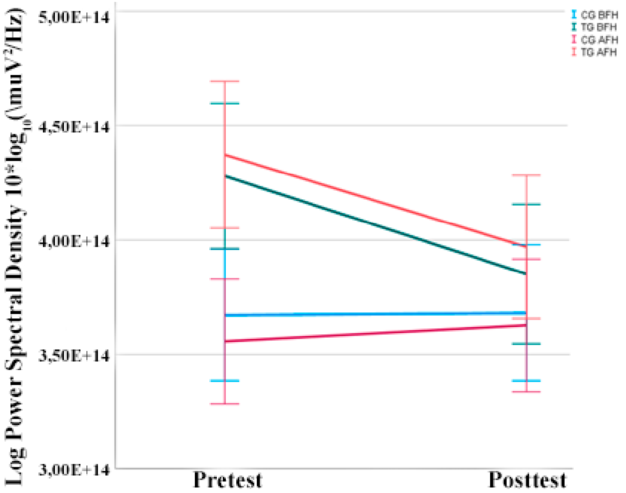

FIGURE 5 Showing mean Beta power for TG and CG at pretest and posttest, for both BFH and AFH.

To further analyze the change in Beta power for TG, a Wilcoxon signed ranks test was used to analyze the average Beta power at all AOIs, giving the results shown in table 3.

TABLE 3 Showing average Beta power along with significance value for all AOIs, at both BFH and AFH.

AOI	Time	Average Power pretest	Average Power posttest	p-value
Frontal	BFH	3,71E+14	3,38E+14	0,973
Frontal	AFH	4,34E+14	3,43E+14	0,237
Left temporal	BFH	5,05E+14	3,51E+14	0,039*
Left temporal	AFH	5,10E+14	4,21E+14	0,162
Left central	BFH	4,33E+14	4,30E+14	0,673
Left central	AFH	4,32E+14	4,32E+14	0,741
Midline	BFH	5,11E+14	5,44E+14	0,324
Midline	AFH	5,01E+14	5,46E+14	0,229
Right central	BFH	4,44E+14	3,36E+14	0,090
Right central	AFH	4,39E+14	4,05E+14	0,579
Right temporal	BFH	3,22E+14	2,63E+14	0,148
Right temporal	AFH	3,23E+14	2,69E+14	0,386
Occipital	BFH	4,39E+14	4,05E+14	0,524
Occipital	AFH	4,32E+14	4,02E+14	0,615

* = p < 0,05

The results from table 3 show how the change in Beta power from pre- to posttest was mainly due to a significantly reduced Beta power at the left temporal area of the brain at BFH (p = 0,039).

4 | Discussion

The primary purpose of this experimental study was to test whether training golf putting in VR could alter the cortical activity, and whether a transfer of learning would occur between VR training and a real-life putting test. To this end, the study compared a VR training group to a control group in overall EEG frequency power, which can reflect motor programming processes during motor preparation. The main findings of this study were that the VR training group showed no significant change in any EEG frequency bands compared to the control group but increased their real-life putting score after the intervention.

4.1 | Cortical activity

The results of the study found no significant changes in cortical activity, and therefore does not support the psychomotor efficiency hypothesis (Hatfield and Hillman, 2001; Hatfield, 2018). This contradicts the changes found in other studies performing similar protocols with real-life training (Zhu *et al.*, 2011; Gallicchio, Cooke and Ring, 2017). The observed changes in cortical activity in said studies emerged from a decreased alpha power in the frontal region, and a higher power in the temporal and occipital regions, suggesting an allocation of neuronal resources. Similar findings were partly seen in the present study as the Beta power in the left temporal side of TG was significantly lower at BFH after the intervention. The reduced Beta power is interesting as it has been shown how oscillations in the Beta-band is modulated in relation to voluntary movement (Jasper and Penfield, 1949). The decrease of Beta power at BFH agrees with other studies, showing a decrease in Beta power in the preparation phase, and could reflect cortico-cortical communication or an anticipatory increase of attention (Zaepffel *et al.*, 2013). However, as the studies mentioned above generally found changes while investigating the centroparietal area and the present study only found changes for the left temporal area, it is difficult to say if the changes correspond accordingly.

The present study showed improved results in putting performance but no changes in cortical activity, which contradicts general findings in other studies on training and cortical activation (Slobounov *et al.*, 2007; Cooke *et al.*, 2014; Gallicchio, Cooke and Ring, 2017). The reason for the incoherent results might lie in the method used to define the onset of the golf putts. As described in the method, a digital calculation based on the built-in accelerometer was used to determine when the subject performed a golf putt. The movement was carefully investigated, but as all subjects move differently, the calculation was not sure to give the perfect time of the golf put, which is also shown in the calculation not registering all 50 putts for every subject. This issue could have caused a wrong selection of data, which in the end could have caused some interference in analyzing the actual cortical activity around the golf putt (Nuwer, 1988).

The incoherent results might also stem from the training period not being long enough to promote changes in cortical activity. Looking at results from prior studies, it is seen that most of them are comparing experts and novices (Baumeister *et al.*, 2008) or examining 12-15 weeks of training (Landers *et al.*, 1994; Kami *et al.*, 1995) and only few are carried out with shorter training periods of just three to six sessions of practice (Zhu *et al.*, 2011; Gallicchio, Cooke and Ring, 2017). However, as there has been found a change from three training sessions in the study by Gallicchio (2017), the incoherent results between cortical activity and golf putting performance might be due to the difference in visual depth and feel in the transition from VR to real life golf putting, making it hard to translate the learned skills from VR to real life (Kramida, 2016; Düking, Holmberg and Sperlich, 2018).

4.2 | Putting performance

The putting performance results from this study shows how it is possible to transfer skills from VR to real life, and presumably transfer both movement and perceptual elements (Baker and Côte, 2006). These results confirm and add to the findings of other studies that VR can be an effective training method transferable to real life performance (Seymour *et al.*, 2002; Neumann *et al.*, 2018; Michalski *et al.*, 2019; Petri *et al.*, 2019; Harris *et al.*, 2020; Cooper *et al.*, 2021).

The results from the present study also adds up to the real life putting study of Gallicchio (2017), where they experienced a significant difference in putting performance from pre- to posttest after three training sessions (Gallicchio, Cooke and Ring, 2017). Though the study by Gallicchio was performed with advanced golfers, the present study confirms a transfer effect from VR training to real life golf putting in novice golfers suggesting VR golf putting being further tested on advanced golfers.

Even though the present study found an increase in performance there were still a couple of factors that presumably could have given a more accurate result. In a study by Harris *et al.*, 2019, they showed how VR comes with a wide variety of challenges, such as conflicting depth information and haptic feedback. This was seen in the present study as the used software was developed for gaming (GolfScope, 2020) and didn't give the opportunity to change the friction of the ball to the grass, along with the subjects using a VR controller with a 124-gram distinction in weight, and a distinct weight distribution to the real golf club. These differences made a clear distinction between VR and real life which in the end could have proposed a problem in transferring the VR putting accuracy to real life putting (Harris *et al.*, 2019).

4.3 | VR putting performance

During VR training, all subjects improved in VR putting performance, with an average improvement across the group matching a linear learning curve. It has been suggested by other studies that training in VR should have an adaptive degree of challenge, which changes depending on the subjects past performance (Michalski *et al.*, 2019). But as the learning curve didn't flatten out, it would seem like the challenge was still fitting for the average subject. The fact that the learning curve didn't flatten out gives an indication that the participants, at the end of the study, still was in the cognitive stage of learning, in which they were still trying to process information in an attempt to cognitively understand the requirements of the motor movement (Fitts and Posner, 1967). That their skill learning was still very much in the first stage of learning, could suggest that the subjects were not yet able to translate the declarative knowledge into procedural knowledge (Adams, 1971), which in the end could be one of the reasons why no change was seen in the cortical activation. However, as there was a big difference between the worst final score (31 balls holed) and best final score (68 balls holed) in VR, an adaptive challenge system might have provided a better transfer of performance, and maybe a visible change in cortical activation.

5 | Future perspectives

Based on findings of the present study, future research should investigate whether the increase in performance after VR golf putting training matches a real-life golf putting training intervention and if improvement is seen in advanced athletes. Furthermore, it would be interesting to examine if a training period where the participants reached a plateau in VR performance, would show an altered cortical activity like the changes seen in real-life golf putting studies.

6 | Conclusion

In conclusion, this study did not show any effect of VR golf putting on cortical activation, but it did show a significant increase in real-life putting performance, suggesting that VR can be used to learn real life skills. Due to these findings, future research should explore longer VR training periods on advanced golfers.

Conflict of interest

There is no conflict of interest to disclose from any of the authors.

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