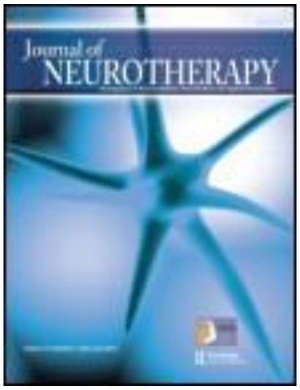


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# Golf Performance Enhancement and Real-Life Neurofeedback Training Using Personalized Event-Locked EEG Profiles

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# Golf Performance Enhancement and Real-Life Neurofeedback Training Using Personalized Event-Locked EEG Profiles

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**ABSTRACT.** *Background.* This study reports on a new method for golf performance enhancement employing personalized real-life neurofeedback during golf putting.

*Method.* Participants ($n = 6$) received an assessment and three real-life neurofeedback training sessions. In the assessment, a personal event-locked electroencephalographic (EEG) profile at FPz was determined for successful versus unsuccessful putts. Target frequency bands and amplitudes marking optimal prefrontal brain state were derived from the profile by two raters. The training sessions consisted of four series of 80 putts in an ABAB design. The feedback in the second and fourth series was administered in the form of a continuous NoGo tone, whereas in the first and third series no feedback was provided. This tone was terminated only when the participants EEG met the assessment-defined criteria. In the feedback series, participants were instructed to perform the putt only after the NoGo tone had ceased.

*Results.* From the personalized event-locked EEG profiles, individual training protocols were established. The interrater reliability was 91%. The overall percentage of successful putts was significantly larger in the second and fourth series (feedback) of training compared to the first and third series (no feedback). Furthermore, most participants improved their performance with feedback on their personalized EEG profile, with 25% on average.

*Conclusions.* This study demonstrates that the "zone" or the optimal mental state for golf putting shows clear recognizable personalized patterns. The learning effects suggest that this real-life approach to neurofeedback improves learning speed, probably by tapping into learning associated with contextual conditioning rather than operant conditioning, indicating perspectives for clinical applications.

**KEYWORDS.** Neurofeedback, peak performance, golf, EEG, personalized, wireless

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The majority of research studies exploring the utility of neurofeedback in sports performance enhancement are noncontrolled group studies or case studies (Landers et al., 1991). Nevertheless, these studies indicate that neurofeedback is a promising method for sports performance enhancement. Hammond (2007) reviewed some of the research in this area and pointed to the potential for the use of neurofeedback in performance enhancement in various sports. He also described some of the limitations of approaches that do not account for individual differences and the different demands of various sports.

Haufler, Spalding, Maria, and Hatfield (2000) reported that marksmen showed less activation when shooting a target as demonstrated by a decrease in fast activity and an increase in synchronization in the alpha band but with a focus in the left central-temporal-parietal areas. Other research for archery (Hatfield, Landers, & Ray, 1984; Salazar et al., 1990) and before golf putting (Crews & Landers, 1993) showed an increase in alpha power (corresponding to a decrease in activation) in the aiming and focusing period, known in the literature as the preparatory period. More important, the relationship between sports performance and EEG measures found increased left-temporal alpha is associated with decreased performance in marksman (Hatfield et al., 1984) and archers (Salazar et al., 1990), but increased right-temporal alpha is associated with increased performance in golfers (Crews & Landers, 1993). In an early study, (Landers et al., 1991) reported that right cerebral hemisphere slow cortical potential (SCP) or Bereitschaftspotential training (suggested to correspond to increased activation) in archery led to a decline in performance in contrast to the group who showed an increase in performance with left hemisphere SCP training, indicating the power to either improve or impair performance via neurofeedback training.

However, different sports and even different tasks within the same sport are likely to require a totally different pattern of activation in the brain and the autonomic nervous system. Furthermore, assessment and training for performance enhancement various electroencephalographic (EEG) frequencies can have a functional significance that is highly variable across individuals. For example, consider the implication of the alpha activity related to optimal response preparation. Based on the work of Klimesch (1999), the individual alpha peak can be defined as the frequency showing maximum power density peak within a large frequency range lasting from 4 to 16 Hz, and therefore the alpha band may or may not fall within the 8 to 13 Hz range as described in some of the EEG and neurofeedback literature. Considering this important factor, the assessment and training of alpha may require a totally different frequency range, which is again personalized and unique to that individual.

We agree with the conclusions made by Hammond (2007) as he suggested that different brains demand different approaches. Simplistic one-size-fits-all approaches to neurofeedback in sports are likely to be ineffective across various tasks and sports. This is also in line with new approaches to clinical treatment such as personalized medicine and the development of the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; American Psychiatric Association, in press) focusing more on individual differences (genotype and neurobiological phenotype) and personalized treatments rather than behavior-based diagnosis and treatment (Gordon, 2007). In addition to the use of personalized approaches, a task-related to real-lifetraining will probably facilitate learning, as new skills are acquired in the context where they need to be exercised.

In the study presented here, we investigated the existence and discriminative power of personal success profiles in the EEG, using a within-subject design comparing successful versus unsuccessful golf putts. To explore whether these personal success profiles were functionally associated with putting skills, we provided participants with real-lifeneurofeedback to see if they were able to improve their putting skills.

## METHOD

### Participants

Six participants participated in the experiment (3 female, 3 male). Participants were all amateur golf players. Their average handicap was 12.3 ($SD = 5.6$).

### *Apparatus*

The assessment took place on the putting range of a golf course (Anderstein, The Netherlands). A table was set up near the putting hole on which recording PCs were placed. The experimenters were seated behind the table. Because weather conditions made it impossible to continue the training outside, not all training sessions were held outdoors. The majority of training sessions were held indoors on artificial grass measuring $145 \times 400$ cm. A putting cup was placed on the artificial grass. A table holding the equipment was placed next to the grass, on the side of the putting cup. The experimenter was seated behind the putting cup. A marker was placed at the 50% successful putting distance.

All EEG recordings and feedback sessions were recorded using the wireless BraInquiry 2-channel PET EEG with active electrodes and BioExplorer software. The PET EEG was attached on the participants' back on an elastic band around the chest. Wires were lead over the participants' backs such that it minimized inconvenience and maximized freedom of movement. The first channel of the PET EEG was used to record EEG from FPz, referenced against linked mastoids $[(A1 + A2)/2]$. The ground was placed on the left side of the forehead. Disposable Silver-Silver-Chloride ($Ag/Ag^{+}Cl^{-}$) electrodes (Arbo H124-SG electrodes, Tyco) were used for EEG recording. All electrode sites were prepared with alcohol and Nuprep.

Ball impact was recorded using a microphone (AV-JEFE TCM 160), which was mounted on top of the putter. The microphone signal was recorded on the second channel of the PET EEG. Participants used their own putter.

### *Procedure*

*Assessment.* All participants first participated in an assessment session. This session was included to determine the participants' personalized event-locked EEG profile. A warm-up round was used to determine the participants' personalized 50% successful putting distance ($PD_{50}$). Participants performed series of 10 putts, which were scored as successful holedor unsuccessful not holed. After each series, the percentage of successful putts in that series was determined. According to this percentage, participants had to increase/decrease their putting distance in the next series. This process was repeated until participants scored 50% accuracy. The distance at which this occurred first was taken as the $PD_{50}$. The $PD_{50}$ was used as putting distance in the assessment of the event-locked EEG profile and during the subsequent trainings.

In the assessment session, participants performed eight series of 10 putts (total 80 putts, approximately 40 successful and 40 unsuccessful) while both EEG and ball impact were recorded. The experimenters recorded the outcome (successful or unsuccessful) manually. These data were used to generate each participant's personal and individual profile using event-locked averaging of the EEG pre- and postball impact in different frequency bands. This provided the individual EEG profiles for successful versus unsuccessful putts, which could vary from participant to participant.

*Training*. During training sessions, participants received feedback on their brain activity. The training consisted of three sessions (over different days) consisting of four series of 80 putts from their $PD_{50}$ in an ABAB design (no feedback–feedback–no feedback–feedback). The feedback consisted of a continuous NoGo tone—delivered to the participant through notebook speakers—that was terminated when the participant reached his or her personally determined optimal EEG profile.

EEG was recorded from FPz referenced against linked mastoids during training. From the EEG, amplitudes of the individually assessed frequency bands were extracted. The NoGo tone terminated when all the amplitudes to be rewarded exceeded the preset reward thresholds, whereas the amplitudes to be inhibited were below the preset inhibit thresholds. Besides the individually determined rewards and inhibits, termination of the tone was prevented during the occurrence of excessive 50 Hz noise, which was used as a correlate of impedance (reflected as $> 10\,\mu$V of 50 Hz), EMG or EEG power—which, on FPz, usually indicates an eye blink. When the tone ceased it was set to be absent for at least 1.5 sec, except when an eye blink occurred.

All instructions were standardized. The participants were instructed to do the following:

1. If they felt ready, initiate putting as soon as possible after the tone ceased.
2. Make the putt within 1.5 sec from the moment when the feedback sound ceased.
3. Carry out the putt when the decision was made to do so, irrespective of the possible return of the NoGo tone.

All putts were scored manually as being successful or unsuccessful.

## RESULTS

### Data Analysis

*Assessment.* The EEG data from the assessment were bandpass filtered using BioReview software (Theta: 4–8 Hz, Alpha: 8–12 Hz, sensorimotor rhythm [SMR]: 12–15 Hz, Beta: 15–30 Hz, Alpha-1: 8–10 Hz, Alpha-2: 10–12 Hz, Beta-1: 15–22.5 Hz, and Beta-2: 22.5–30 Hz). Note that the EEG was also filtered in the SMR frequency band, however given the recording location—of course—this is not SMR but should be seen as low beta. The frequency band amplitudes were averaged locked to the event of ball impact for successful and unsuccessful putts separately (e.g., the EEG data of approximately 40 successful events were aligned on the exact timing of the ball impact and then averaged over the event-related EEG).To establish a personalized training profile, the event-locked amplitude spectra for successful and unsuccessful responses were printed with 1-sec preputt and 0.5-sec postputt interval and rated by two raters (see Figure 1).

### Neurofeedback Training

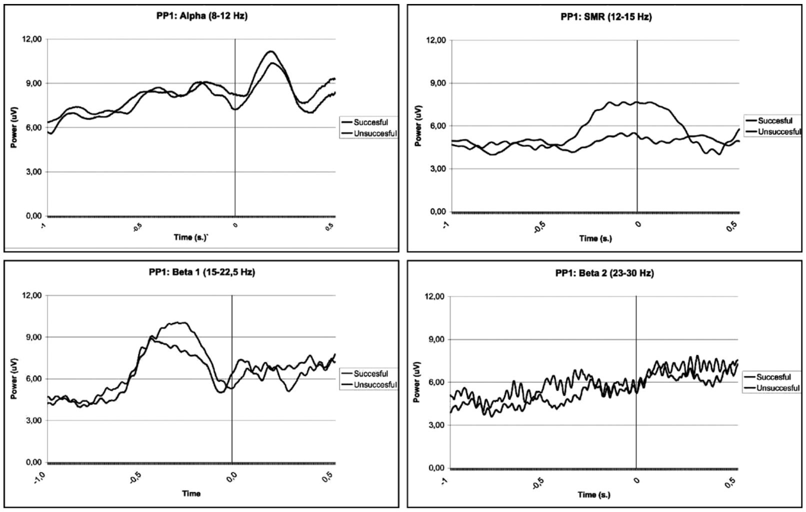
Training results were averaged over participants and evaluated in a $3 \times 2 \times 2$ (Session $\times$ Feedback $\times$ Series) analysis of variance (ANOVA). In addition, post hoc $2 \times 2$ (Feedback $\times$ Series) ANOVAs were carried out for each of the training sessions. Reported effects for ANOVA are Pillai's Trace.

*Assessment.* The average $PD_{50}$ was found to be 149 cm ($SD = 30$ cm). The average percentage of successful putts in the assessment was 48.7% ($SD = 5.1\%$). Event-locked averaging of the EEG revealed a clear EEG pattern for each of the participants where for the successful versus unsuccessful putts clear patterns were observed in the last second before ball impact. As hypothesized, these EEG profiles were quite different for most of the participants. Figure 1 shows three examples of the EEG profiles. The obtained training settings for each participant, which were used in the subsequent training are shown in Table 1. After rating of all the individual profiles, the conclusions of the raters were compared and revealed only one minor difference in the training protocols. Consequently, the interrater reliability was 91%.

*Neurofeedback Training* Accuracy scores for the three training sessions are summarized in Figure 2. A $3 \times 2 \times 2$ (Session $\times$ Feedback $\times$ Series) repeated measures ANOVA was performed on the accuracy scores. The effects of session, $F(2, 4) = 288.068$, $p < .000$, and feedback, $F(1, 5) = 16.757$, $p = .009$, were found to be highly significant. The main effect of feedback indicates significantly larger accuracies in the feedback series compared to the no-feedback series and therefore demonstrates a clear effect of the feedback. The main effect of session indicates that the accuracy performance was different over the three sessions. The main effect of series or interactions was not significant.

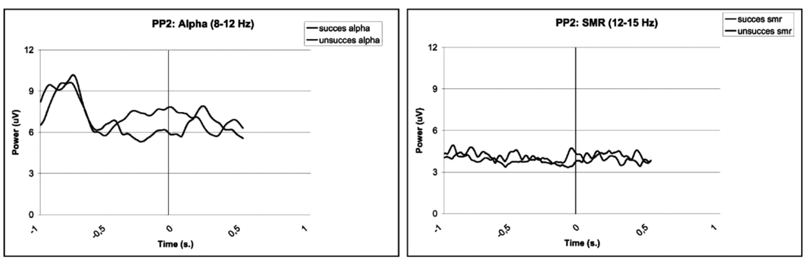
To investigate where these effects occurred, we performed post hoc $2 \times 2$ (Feedback $\times$ Series) ANOVAs for each of the sessions individually. In Session 1, a significant effects of series, $F(1, 5) = 8.378$, $p = .034$, was found. In Session 2, a highly

FIGURE 1. The event-locked amplitude spectra for successful and unsuccessful responses.



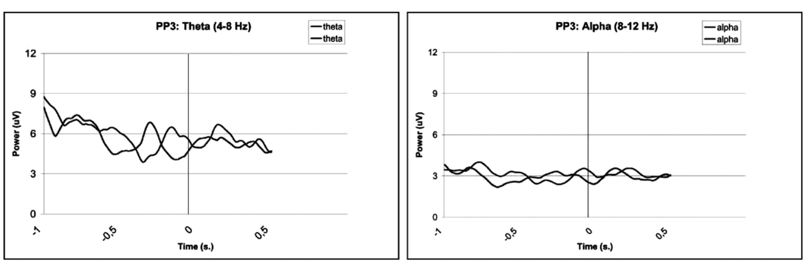

**Subject 1**

This subject shows a very clear pattern in SMR and Beta 1. There were no differences in the Alpha and Beta 2 ranges.




**Subject 2**

This subject shows a very clear pattern in Alpha and a small difference in SMR. There were no differences in the Beta 1 and 2 ranges.




**Subject 3**

This subject shows a shift in Alpha and Theta. There were no differences in the Beta 1 and 2 ranges which could be interpreted as a timing effect; e.g. the preperation started to early.

TABLE 1. The obtained training settings for each participant used during the training.

| Participant | Theta | Alpha | SMR | Beta | Alpha 1 | Alpha 2 | Beta 1 | Beta 2 |
|---|---|---|---|---|---|---|---|---|
| AH | < 18 | < 18 | < 8 | < 15 | | | | |
| AV | < 15 | | < 6 | < 9 | | < 6 | | |
| EB | < 18 | | | < 14 | < 12 | | | |
| FK | < 15 | < 10 | < 8 | | | | < 10 | < 8 |
| HK | < 20 | < 10 | < 10 | < 13 | | | | |
| IW | | < 25 | < 9 | < 10 | | | | |

*Note.* SMR = sensorimotor rhythm.

significant effect of feedback was found, $F(1, 5) = 111.938$, $p < .001$, and post hoc $T$ tests revealed that the first series of the no-feedback condition differed from the first series of the feedback condition, $t(5) = -4.862$, $p = .005$, and the second series of the feedback condition, $t(5) = -6.145$, $p = .002$. No other post hoc differences were found. The ANOVA of the third session revealed no significant effects.

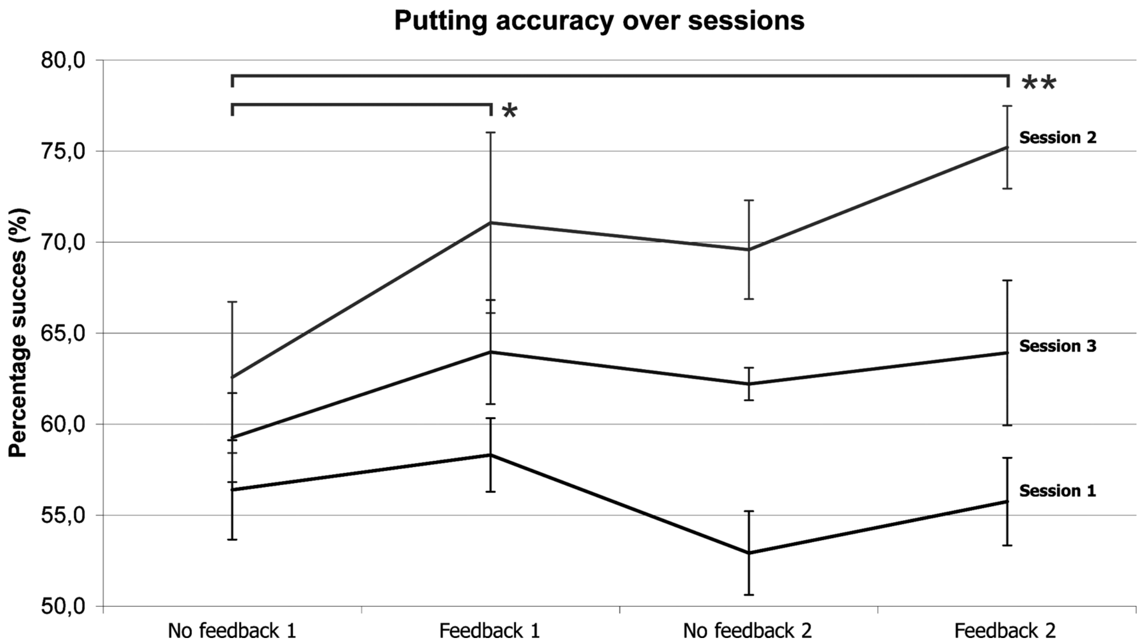
## DISCUSSION

This study showed that differential EEG profiles exist for successful versus unsuccessful golf putts for each individual. Our data indicate a large variability in these success profiles between different participants. Furthermore, we also showed that when participants are trained on their personalized brain profiles related to successful golf putts they can learn to improve their putting performance, demonstrating the relationship between these personal brain profiles and putting performance. This was demonstrated in a controlled ABAB design, showing that participants scored up to 25% more putts in the *feedback condition* (B) compared to the *no-feedback* condition (A). The EEG training location we used was FPz, whereas most published studies have focused on laterality (e.g., right vs. left temporal EEG). In a pilot study, the event-locked averaging method showed clearer patterns than laterality measures (the ECG and 2 channels EEG), and therefore the 1 channel of EEG was chosen for this study.

Previous studies investigating success profiles in sports people have mainly focused on group data (Crews & Landers, 1993; Hatfield et al., 1984; Konttinen, Landers, & Lyytinen, 2000; Landers et al., 1991; Salazar et al., 1990). In this study we clearly demonstrated that *different* people under similar task conditions show personalized success patterns in the EEG in the 1-sec interval prior to putting a golf ball. Some participants in our study indeed showed increased prefrontal alpha before ball impact as the optimal mental state, as previous literature suggests (Crews & Landers, 1993; Salazar et al., 1990). However, in other participants, increased SMR or low beta (Participant 1 in Figure 1) was associated with the optimal prefrontal brain state. Others showed a phase shift in their prefrontal alpha and theta activity (Participant 3 in Figure 1) for unsuccessful putts (compared to the successful putts), suggesting that for these participants the timing of the activity pattern is poor in unsuccessful putts. From these data it cannot be concluded whether these personal profiles are related to the individuals' alpha peak frequency or reflect different underlying neural networks for all participants. The example of Participant 3 tends to suggest the latter possibility, but more research is required to investigate that further.

From Figure 2 one can see that the trend for increased performance is present in Session 1 but does not reach significance, as participants had difficulty during the feedback in that it was very hard to learn to putt on command rather than putt at will in their own routine. In the second session, highly significant differences were found between the feedback and no-feedback condition. The decline in performance in the second no-feedback series excludes that nonspecific (practice) effects alone could account for the increase in performance. A tentative explanation of the results from Session 3 could be that the Feedback 1 condition in served as a reminder, because an (insignificant) increase in performance is observed. In the remainder of Session 3 the participants' performance remains stable over conditions, suggesting they learned to invoke their personalized success profile. The results showed a significant main effect of session. The putting accuracy in Session 1 was lower as compared to Sessions 2 and 3. However, because Session 3 resulted in lower accuracies than Session 2, this effect cannot be explained as a learning effect alone. A probable explanation for the effect of session concerns the training location. We were unable to finish all training sessions in the same location but switched locations from outdoors to indoors in the second session for most participants because of weather conditions. It was observed that in indoor locations the participants were able to achieve

FIGURE 2. The putting accuracy over four sessions.




higher accuracies compared to the outdoor location. These differences between sessions should therefore be interpreted as related to external factors such as indoors versus outdoors but also to individual factors such as having a good or a bad day. The real training effect is demonstrated by the controlled ABAB design, effectively controlling for these interday differences.

The event-locked averaging of EEG spectral content proved to be a valid and promising tool to investigate personalized brain profiles related to optimal performance, in a within-subject design. The difference between this method and event-related potentials (ERPs) is that in this study EEG power of different frequency bands was averaged as opposed to averaging the raw signal seen in ERP research. We propose that this method could also be used very well in clinical applications (e.g., epilepsy and attention deficit hyperactivity disorder [ADHD]). In ADHD, for instance, with this method attentive and inattentive states can be dissociated within the individual, and attentive states could be rewarded in real life based on this personal profile. For epilepsy, participants could be followed long term to obtain a personal EEG profile serving as a marker for seizures (e.g., excess negativity, correlation dimension, SMR). On detection of the obtained personal marker, the patient could be warned of a seizure about to come and initiate precautionary measures (e.g., the neurofeedback at that specific moment, in real life) to counteract the epileptic seizure.

We hypothesize that the learning procedure employed in this study is more related to classical conditioning rather than a pure operant conditioning. The contextual situation (standing with the putter on a green with the putting hole in view and ready to putt) is used as a contextual stimulus and is paired to the optimal mindset. This learning procedure relies more on pairing the optimal mindset to the contextual situation (classical conditioning) than on shaping the behavior (operant conditioning). This might explain the fast acquisition of the learned skill as evidenced by the absence of a difference between the feedback and no feedback series in Session 3. This also implies that this acquired skill is only learned for this contextual situation and not for others, whereas regular neurofeedback often requires overtraining to achieve generalization whereby the self-regulation skills can also be applied in daily live (e.g., SCP control). Therefore, the real-life methodology we applied in this study holds great promise for clinical applications by having a clinical effect within fewer sessions and being more specific with respect to the contextual situation in that no overlearning is required and skills are acquired for only situations where they are required. However, the usability of this approach should be investigated further for clinical applications. One particularly interesting issue would be to see whether with increasing experience the duration of the tone would decrease. This was not been monitored in this study, yet a decrease would further support the validity of this learning procedure, comparable to the early studies of Kamiya (1968), who taught participants to initiate a state change.

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