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Real-Time Index for Predicting Successful Golf Putting Motion Using Multichannel EEG

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Abstract—**A skill in goal-directed sport performance is an ability involving with many factors of both external and internal concernment. External factors are still developed while internal factors are challenged topic to understand for improving the performance. Internal concernment is explained an effective performance as estimation, solving strategy, planning and decision on the brain. These conjunctions are relevant to somatosensory information, focus attention and fine motor control of cortical activity. Five skilled right-handed golfers were recruited to be subjected of studying the criteria on how to predict golf putt success. Each of their putts was calculated in power spectral analysis by comparing to the pre-movement period. Successful and unsuccessful putt were classified by focusing on the frontal-midline(Fz), parietal-midline(Pz), central midline(Cz), left central(C3) and right central(C4) which supported by few consistency studies that they are related to a primary sensory motor area, focus attention and working memory processing. Results were shown that high alpha power on C4, theta power on Fz, theta power and high alpha power on Pz can be calculated to use as index of predicting golf putt success. Real-time monitoring system with friendly GUI was proposed in this study as promising preliminary study. Expected goal in the future is to apply this real-time golf putting prediction system into a biofeedback system to increase the golf putting's accuracy. However, it still needs more subjects to increase credibility and accuracy of the prediction.**

I. INTRODUCTION

Practicing and developing in any skills to increase a performance are a desire in every field especially in sport science. Challenge studies in process of optimized skill acquisition were revealed for decades. An approach in sports performance was focused on difference between novice and experts in a specific task. It was understandable explained as an expert can filter relevant information of both internal and external for motor task better than novice who also does not know the way how to focus on task ahead [1].

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This informational relevance is in process of the brain. Therefore, electroencephalography (EEG) can be used to monitor the electro-cortical changes regarding this relation. Importance of attention was initially studied the conjunction between preparation and action period in sports which was in archery [2], in rifle shooting [3] and in golf [4]. EEG also provides changes in brain state describing development in cognitive, visuomotor tasks [5-7].

Golf putting was selected as a goal-directed sport performance to study in effectiveness of estimation, solving strategy, planning and making decision. To investigate brain state changes during continuous tasks is rather studied as an event-related and also needed to transform EEG to evaluate a power of each brain band in spectral domain.

In the last decade, there are two preferable ways in the study of golf putting performance. First is to study a performance regarding the workload of memory and attention level during a putting task. Baumeister et al. (2008) found higher frontal Theta power values and higher parietal alpha-2 power was increased in expert golfer compared to the novice [8]. In the working memory concept, these can be represented that experts had more focus attention (higher frontal Theta power) and more economical effort of sensory information processing (higher parietal alpha-2). In additional, parietal theta power had also increased related to complex visuomotor task which associated to higher skill level supported by Dolce and Waldeier [9].

Second is a study about the relation between successful putts and alpha-2 power in the frontal midline and the right sensorimotor brain area. Babiloni et al. (2008) found decrement of alpha-2 in successful putts is relatively more decrease than unsuccessful putts especially at C4 [10]. Authors showed the linear correlation between the decrement of alpha-2 power and error from the hole which leading to the conclusion that this decrement can be used to predict the golf putt outcome.

However, those founds were still an offline procedure which cannot used as real-time prediction. This paper wants to develop those phenomenon to predict an online golf putt success with graphical user interface (GUI) and verified those founds to then be assembled as an predictable index of golf putt success.

II. METHODS

A. Subjects

Five male volunteered experienced golfers with mean age 48.2 ± 8.3 years (ranges: 34-60 years), mean weight 71.2 ± 8.73 kg (ranges: 63-85) and mean height 169.8 ± 4.45 cm (range: 164-175) were recruited. They are 3 low handicap golfers (14.67 ± 2.49) and 2 professional golfer. All subjects were right-handed golfer who had been practicing golf for 16 ± 13.81 years and playing golf 17 ± 6.63 h/week. All participants were healthy and had no neurological disorder. They were informed methods and had consented to be subjects with pleasure.

B. *Experimental Procedure and Recording*

Subjects were asked to stand on a green carpet (1.5 m x 3 m) that the green cover was acceptable under professional golfer advice. The distance between putting point and hole was 2.5 m. Hole diameter was 108 mm (standard). Putter was brought by each golfer to avoid usage error from unfamiliarity. Each subject was asked to perform putts for 10 min for making familiar with green before starting an experiment. An experiment was split into 5 sets. Between each set subjects was asked to relax for 1 min. In each set was composed of 10 putts and each putt was an interval of about 20 s. Each subject was told to freely relax when they felt stiff.

During each putt EEG data was recorded with the ActiveTwo BioSemi™ system (BioSemi, Amsterdam, Netherlands). Recordings were taken from 32 scalps electrodes on basis of the 10/20 system, digitized at 256 Hz and electrode offset were kept below 20 mV. Signa Gel (Parker Labs, Fairfield, NJ) was used to connect an electrical signal between each electrode and scalp. Each electrode was referred to a common mode sense (CMS) electrode. EEG derived from ActiveTwo BioSemi system was monitored and processed with software written in LabVIEW™.

C. *Spectral Analysis and ERD/ERS Computation*

EEG was recorded continuously from 7 scalp positions (Fz, F3, F4, Cz, C3, C4, Pz) preprocessed by the Laplacian method via their 4 surrounding electrodes to get their local potential signals. Zero phase filtering was applied in each EEG signal (4-35 Hz bandpass filter) to reject the motion and eye/head movement artifacts due to putt. Then the Fast Fourier Transform (FFT) with 50% overlapping 256-sample Hanning windows was applied on each filtered EEG signals to find the absolute power on each different frequencies: Theta (4.75-6.75 Hz), Alpha-1 (7-9.5 Hz), Alpha-2 (9.75-12.5 Hz) and Beta (12.75-35 Hz).

The power value of each frequency band was calculated by comparing putt period with reference period as in spanning of task. At 0 second (s.) was when putter impacted the golf ball, hence -1 s. to 0 s. was recorded as putt period and reference period was when subject felt relax that was recorded at -5 s. to -4 s. before each putt. The results were in percentage of event-related that can be negative value which called event-related desynchronization (ERD) or positive value which called event-related synchronization (ERS) as in (1).

$$ERD/ERS(\%) = \left(\frac{putt - ref}{ref}\right) \times 100 \qquad (1)$$

Then each ERD/ERS was analyzed and discussed to use as index for real-time predicting percentage of golf putt success by monitoring in LabVIEW™.

III. RESULTS

A. *ERD/ERS Analysis*

EEG data from 7 electrode scalps, i.e. frontal-midline (Fz), left frontal (F3), right frontal (F4), parietal-midline (Pz), central midline (Cz), left central (C3) and right central (C4) were acquired to find the ERD and ERS compared with the reference period. As comparing the results with previous study on the performance during golf putt, there are no significant changes relating to the success of golf putt in F3, F4, Cz and C3. Conversely, ERD/ERS in Fz, C4 and Pz were shown relevant changes as plotted versus frequency on x-axis as shown in Fig.1-3.

Between successful and unsuccessful putts, more ERD was shown on 10-12 Hz frequency, or alpha-2(mu band), over the right primary sensorimotor cortex (C4 electrode) shown in Fig.1. However, ERD on beta rhythm seemed to have no correlation with the success.

Frontal area (Fz electrode) demonstrated the ERS on 4.75-6.75 Hz (theta band) in successful putts more than the unsuccessful putts as shown in Fig.2.

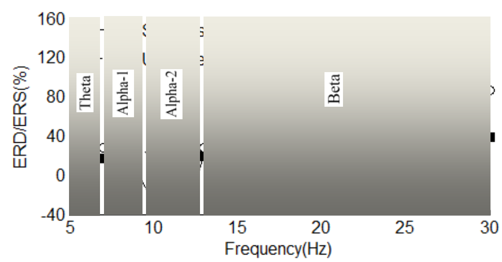

Figure 1. Mean ERD/ERS in the range 5-30 Hz for successful and unsuccessful golf putt on the right primary sensorimotor cortex (C4 electrode)

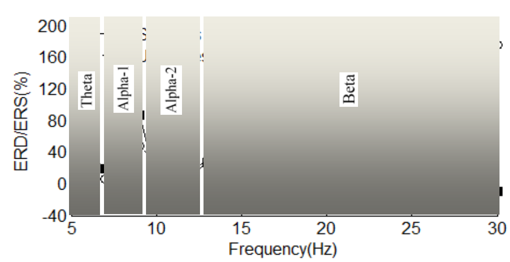

Figure 2. Mean ERD/ERS in the range 5-30 Hz for successful and unsuccessful golf putt on the frontal-midline (Fz electrode)

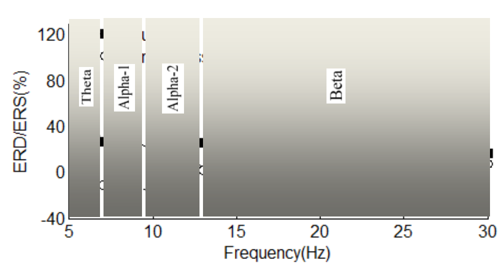

Figure 3. Mean ERD/ERS in the range 5-30 Hz for successful and unsuccessful golf putt on the parietal-midline (Pz electrode)

On parietal-midline (Pz electrode) shown in Fig.3, there was more ERS on theta power in successful putts than unsuccessful putts. Additional, there was more ERS on alpha-2 in successful putts than unsuccessful putts.

Mean ERD/ERS power value of theta in Fz, alpha-2 in C4, theta and alpha in Pz were plotted as column chart for the comparison of successful and unsuccessful putts as shown in Fig.4. Grand average ERS at Fz (Theta) of successful and unsuccessful putts were 20.45 ± 15.33 and -0.53 ± 14.26 respectively. Grand average ERD at C4 (Alpha-2) of successful and unsuccessful putts were -26.02 ± 20.22 and -2.24 ± 14.45. Grand average ERS at Pz (Theta) of successful and unsuccessful putts were 37.58 ± 18.02 and 4.35 ± 22.28. And grand average ERS at Pz (Alpha-2) of successful and unsuccessful putts were 10.74 ± 10.17 and 2.01 ± 17.85. Each mean ERD/ERS power value was quite differentiated between successful and unsuccessful putts. For these reasons, they could be designed as an index of predicting the success. Thus the system was designed by using those four ERD/ERS power value differences.

B. *Weighted ERD/ERS Prediction Equation*

To design the golf putt success predicting system, the energy which was an area under interested ERD/ERS power value was counted. The summation of each area was calculated as a fraction between the mean of successful ERD/ERS (which was calculated equaled to 1) and the mean of unsuccessful ERD/ERS (which was calculated equaled to 0) on each EEG data. Then those 4 fractional numbers were weighted for getting balanced proper value as in (2).

$$\%\text{Success} = \left(\frac{1}{\sum_{i=1}^{4} w_i} \sum_{i=1}^{4} w_i \cdot E_i\right) \times 100 \quad (2)$$

where w_i indicated weight and E_i indicated an energy which was area under ERD/ERS power value. i = 1 to 4 indicate Fz (Theta), C4 (Alpha-2), Pz (Alpha-2) and Pz (Theta), respectively. Weight on Fz (Theta), C4 (Alpha-2) and Pz (Alpha-2) were set equal to 1 while the weight of ERS on Pz (Theta) equaled to 0.5. These weights were initially defined by considering previous researches about golf putt performances [8, 10]. Weight of ERS on Pz (Theta) had weakly insisted on reference contrarily to the others. Energy of each ERD/ERS power value was calculated as shown in (3), (4), (5) and (6). For example, an area of mean successful putts on Fz in Theta band was equaled to 20.446 while an area of mean unsuccessful putts on the same Fz in Theta band was equaled to -0.529. These were defined as 1 and 0 respectively. If calculated area of Fz (Theta) was more than 20.446, its fraction was given by 1. Conversely, fraction was given by 0 if an area was less than -0.529. And if an area value was between -0.529 and 20.446, a fraction was calculated as linearly value between 0 and 1 as in (3), i.e.

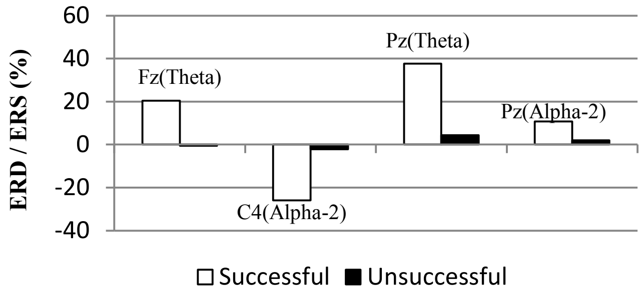

Figure 4. Mean power values of ERD/ERS on Fz (Theta), C4 (Alpha-2), Pz (Theta) and Pz (Alpha-2) comparing with successful and unsuccessful putts.

$$E_{\theta,Fz} = \begin{cases} 1 & ; \quad E_{\theta,Fz} \geq 20.446 \\ \frac{E_{\theta,Fz}+0.529}{20.975} & ; \; -0.529 < E_{\theta,Fz} < 20.446 \\ 0 & ; \quad E_{\theta,Fz} \leq -0.529 \end{cases} \quad (3)$$

$$E_{\propto-2,C4} = \begin{cases} 0 & ; \quad E_{\propto-2,C4} \geq -2.242 \\ \frac{2.242-E_{\propto-2,C4}}{23.774} & ; \; -26.016 < E_{\propto-2,C4} < -2.242 \\ 1 & ; \quad E_{\propto-2,C4} \leq -26.016 \end{cases} \quad (4)$$

$$E_{\propto-2,Pz} = \begin{cases} 1 & ; \quad E_{\propto-2,Pz} \geq 10.739 \\ \frac{E_{\propto-2,Pz}-2.008}{8.731} & ; \; 2.008 < E_{\propto-2,Pz} < 10.739 \\ 0 & ; \quad E_{\propto-2,Pz} \leq 2.008 \end{cases} \quad (5)$$

$$E_{\theta,Pz} = \begin{cases} 1 & ; \quad E_{\theta,Pz} \geq 37.581 \\ \frac{E_{\theta,Pz}-4.3523}{33.229} & ; \; 4.352 < E_{\theta,Pz} < 37.582 \\ 0 & ; \quad E_{\theta,Pz} \leq 4.3523 \end{cases} \quad (6)$$

IV. REAL-TIME IMPLEMENTATION SOFTWARE

To further practically employ the golf putt success prediction in real-time, the software was developed via LabVIEW™ as shown in Fig.5. The multi-channel EEG signal that was acquired from the I/O port of the ActiveTwo BioSemi™ system was calculated according to the methods in Section II.C and III.B. The lowest chart in Fig.5 was derived from a trigger input from infrared sensor to point the time at which golf ball was impacted for defining the putt time and reference time using to calculate in Section II.C. The vertical bar on the right of Fig.5 was the progress bar showing golf putt successful percentage.

After golf putting, EEG signals were measured and then calculated in (2) before shown as percentage in vertical bar in Fig.5 in real-time. Sometimes, it was unsuccessful putt even though the software showed high percentage of golf putting success. In contrast, it could be successful putt when the software showed low percentage success. High percentage prediction did not mean successful putt, it meant there was more probability of golf putting success. From the experiment, if the software predicted higher than 50% of golf putting success, the probability of that putt could be expected.

V. CONCLUSIONS

In this study, we investigated the method of predicting the golf putt success in professional golfers. ERD/ERS at which the professional golfer was putting was compared with ERD/ERS at the reference which golfer was stand still before each putt. Frontal-midline Theta power, right primary sensorimotor Alpha-2 power, parietal-midline Theta and Alpha-2 power were chosen to investigate. These EEG data were studied from previous researches that were insisted having correlation to golf putt success. This study verified those results that these 4 EEG data can be used as the index to discriminate between successful and unsuccessful putt. For frontal-midline theta, it had been suggested that it is related to focus attention [3, 5]. Baumeister [8] found increased higher frontal-midline Theta power in professional compared with novice which had less concentration in task than professional golfer. Therefore, this successful putt was closely related to having more focus attention.

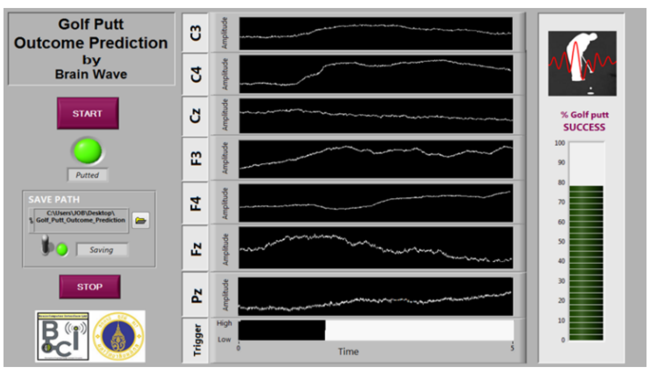

Figure 5. Graphic User Interface of Real-Time Prediction Software

Parietal-midline alpha-2 power was also increased in successful putt which meant golfer had used less neuron in performing golf putt compared with unsuccessful putt. Less neuron used reflected knowing the way to putt well or no need to think much. This found was consistent with the study of Gevins et al. (1997) who found increased alpha-2 power of cortical resources after skill development in cognitive task [11]. And Baumeister et al. (2008) found higher alpha-2 in this EEG position on professional compared to novice.

Increased Theta power on parietal-midline in successful putt compared to unsuccessful putt was involved with more complex visuomotor task during golf putt supported by Dolce et al. (1974) and Fournier et al. (1999) who found this increment is related to visuomotor behavior [9, 12].

Alpha-2 power decreased on right primary sensorimotor cortex (C4) of successful putt was supported by Babiloni et al. who found linearly decrease of Alpha-2 power in this EEG data versus error from the hole. Even though Alpha-2 ERD at C4 in this study had less decreased than their study, difference between successful and unsuccessful can still discriminated. This may be caused of subjects had listened any sounds such as man's voice occurred during testing which similar to actual condition.

Real-time prediction software shown in Fig.5 can be used to preliminary predict the golf putt success. The result was shown satisfied for preliminary study. However, the exclusion of this study was the subjects had to have highly skill of golf putting, so the study could only be focused on informational activities of the brain. Moreover, it still needs more subjects to increase more accuracy and credibility.

This present study is expected to apply in the biofeedback system for helping to increase golf putting performance as Terry et al. (2006) who used their EEG criteria of beta rhythm for visual and auditory reinforcement when the subject's EEG signals met the criteria [13].

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