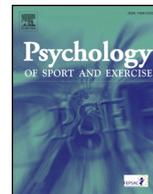




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Experts' successful psychomotor performance was characterized by effective switch of motor and attentional control

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ABSTRACT

Objectives: This study proposed that Mu (8–13 Hz) and SMR (12–15 Hz) readings in the sensorimotor cortical area can be used to investigate the cognitive mechanisms underlying optimal motor performance.

Design: This study used a within-subject design.

Method: Forty expert golfers were recruited to perform 60 putts while their EEGs were recorded. The putting distance was chosen to ensure that approximately 50% of all putts would be missed so that there was a need for constant adjustments to be made during performance. Successful performance was defined as the ball going in the hole.

Results: (a) Lower Mu power in Cz, and alpha power in Pz and Oz were observed for successful performances compared with unsuccessful performances at T1 (–2000 ~ –1000 ms); (b) Higher SMR power in Cz was observed for successful performances relative to unsuccessful performances at T2 (–1000 ~ 0 ms).

Conclusions: These findings not only support the multi-action plan model (MAP) and the psychomotor efficiency hypothesis, but also reveal the temporal dynamics of the cognitive mechanisms in an optimal-controlled state.

1. Introduction

The dual-process framework suggests that human behavior is controlled by two types of cognitive processing (Evans & Stanovich, 2013; for a review, see; Furley, Schweizer, & Bertrams, 2015), autonomous processing that reflects fluent performance and effortless attentional control in task-relevant conditions, and controlled processing that requires working memory to carry out intentions or action plans (i.e., adjust habits of spontaneous performance). The latter has been characterized as engaging in goal-directed allocation of cognitive processing in response to internal and external cues for dealing with novel problems, difficult situations, and unexpected events (Furley et al., 2015). The dual-process theory's default-interventionist model assumes that human behavior appears to alternate between the two modes of

cognitive processing in different contexts (Evans & Stanovich, 2013; Furley et al., 2015; Glöckner & Witteman, 2010).

Bortoli, Bertollo, Hanin, and Robazza (2012) anticipated this hypothesis in the sports domain with their multi-action plan (MAP) intervention model. This model defines four different types of performance-related states: an optimal-automatic state (Type 1), an optimal-controlled state (Type 2), a suboptimal-controlled state (Type 3), and a suboptimal-automatic state (Type 4; Bortoli et al., 2012), each functional or dysfunctional performance being a combination of different cognitive processes and unique neural patterns (for a review, see di Fronso, Robazza, Bortoli, & Bertollo, 2017). Robazza, Bertollo, Filho, Hanin, and Bortoli (2016) found different patterns of perceived control and hedonic tone in performance states, with expert shooters being able to switch between controlled and automatic processing depending on

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the requirements of the situation. Furthermore, Bertollo et al. (2016) and di Fronso et al. (2016) employing event related desynchronization/synchronization (ERD/ERS) analysis in the theta, low and high alpha bands found: (a) more theta ERS activity in visuo-motor attentional networks (Fpz Fc2 Cp2 Cp6) in Type 1, Type 2, and Type 4 states, reflecting more sustained attention on the target with top-down processes; (b) more alpha ERD at C3 in Type 2 and Type 3, reflecting more right finger/hand control; (c) more alpha ERD at fronto-parietal areas in Type 2 performance, reflecting more activity of visuo-spatial attention. These findings are in keeping with the idea of psychomotor efficiency, which implies either less interference in the central motor control processes during cognitive-motor behavior (similar to the Type 1 state) or adaptive recruitment of essential task-specific neural processes under more challenging conditions (similar to the Type 2 state; Hatfield, 2018; Hatfield & Hillman, 2001) and suggests that the MAP model is an useful framework for understanding the psychomotor processes related to reaching and maintaining optimal performance in sports (for a review, see Robazza & Ruiz, 2018), especially in the Type 2 state (Bortoli et al., 2012). However, a more detailed delineation of the essential cognitive processes such as the motor control and task relevant attention is needed to further understand the complex and dynamic cognitive mechanisms underlying the Type 2 state.

Psychomotor performance such as golf putting requires coordination between attention and motor control (Perkins-Ceccato, Passmore, & Lee, 2003). Both attentional focuses require automatic as well as controlled forms of processing when the chance of failure is more than 30–50% (Babiloni et al., 2008; Cheng, Huang et al., 2015). That is, in the difficult task, the athlete needs to pay attention on the core components of the action and to appropriately control attention so as to achieve a Type 2 state and avoid moving to a Type 3 state (Bertollo et al., 2013). For instance, less interference in motor processing is required for a skilled golfer to maintain attentional focus on the target before putting (Perkins-Ceccato et al., 2003). Previous studies have indicated that adaptive task-related attention allocation results in better performance in golf putting (Cheng, Huang et al., 2015; Poolton, Maxwell, Masters, & Raab, 2006), golf pitch shots (Wulf & Su, 2007), and golf chip shots (Bell & Hardy, 2009). Motor control is required for effective guidance (Cooke et al., 2014) and adjustment of movements (Mathers & Grealy, 2014). Previous studies have indicated that golfers need to apply the correct force in the required direction (Craig, Delay, Grealy, & Lee, 2000; Delay, Nougier, Orliaguet, & Coello, 1997), whereas fundamental actions such as balance before putting can be automated and consistently reproduced in the successful performance (Babiloni et al., 2008). Nevertheless it is possible that there may be co-activation of both components during motor preparation (Bertollo et al., 2016; Wulf, 2016), and simultaneous measurements of both components would shed light on the complex psychomotor processing underlying Type 2 state (Toner & Moran, 2014).

EEG measurement has been widely adopted to examine the dynamic nature of psychomotor processes in expert's performances. In what has become a classical study, Hatfield, Landers, and Ray (1984) reported a progressive increase in left temporal alpha as elite shooters approach the trigger pull. Subsequent studies examining alpha in the left temporal area and other parts of the brain (Babiloni et al., 2008; Cooke et al., 2014; Deeny, Hillman, Janelle, & Hatfield, 2003; Del Percio et al., 2009; Hatfield et al., 2013; Loze, Collins, & Holmes, 2001), theta (Chuang, Huang, & Hung, 2013; Kao, Huang, & Hung, 2013, 2014), and sensorimotor rhythm (SMR; Cheng et al., 2017) also have been reported. In particular, the sensorimotor Mu rhythm (8–13 Hz; sensorimotor information) and SMR (12–15 Hz; somatosensory information) are especially relevant to the examination of the psychomotor processes during motor preparation (Babiloni et al., 2008; Cheng, Huang et al., 2015; Cheng, Hung et al., 2015). Although the Mu frequency band overlaps with SMR, they have been associated with different functions. Mu power reflects cognitive resources allocation to response motor programming (Pineda, 2005) during the execution of goal-directed

actions and observations (Cannon et al., 2014). For example, Denis, Rowe, Williams, and Milne (2017) showed that lower Mu power in Cz, rather than parietal and occipital alpha, was associated with successful movement identification. Similarly, in a meta-analysis, Fox et al. (2016) showed that significantly lower Mu in Cz occurred during execution (Cohen's $d = 0.46$, $N = 701$) and observation of action (Cohen's $d = 0.31$, $N = 1508$). In sports, previous studies have indicated that lower Mu power in Cz was associated with motor control such as a corrective action relating to previous movement errors (Cooke et al., 2015) and a resulting successful putting performance, particularly during difficult tasks (Babiloni et al., 2008; Cooke et al., 2014).

On the other hand, higher SMR power was associated with less interference in motor processing (Cheng, Huang et al., 2015; Cheng, Hung et al., 2015; Kober et al., 2015) and resulted in better attention-related task performance (Doppelmayr & Weber, 2011; Gruzelić, Inoue, Smart, Steed, & Steffert, 2010). Cheng et al. (2017) showed that the SMR tends to be higher in more accurate aiming performances. Furthermore, the causal relationship between SMR and golf putting performance is supported by the finding that increased SMR, as a result of neurofeedback training, led to improved golf putting performance in skilled golfers (Cheng, Huang et al., 2015). Therefore, lower Mu and higher SMR in Cz may reflect an effortful but functional Type 2 state as defined by the MAP model.

The primary objective of the current study was to examine the essential attention and motor control processes underlying this controlled state. Based on previous studies and the MAP model, we expected that the temporal dynamics of brain activities (i.e., Mu and SMR power) were related to putting performance. Specifically, it was hypothesized that lower Mu power followed by higher SMR power would be observed in successful putting performances (i.e., Type 2 state) as compared with unsuccessful performances (i.e., Type 3 state).

2. Methods

2.1. Participants

The number of participants recruited was determined by means of power analysis software (G*Power 3.1) using a repeated measures MANOVA with $\alpha = 0.05$, power = 0.80, and effect size = 0.36 (Cheng et al., 2017; Cooke et al., 2014). Accordingly, the minimum recommended sample size was calculated to be 32 participants. Forty expert golfers (Female: 14, Male: 26, Mean age = 21.06 ± 2.38) with national level competition experience were recruited. The mean handicap was 0.4 (SD = 4.24). All participants recruited met the following basic criteria: (a) no history of neurological disease, (b) right-handed (Oldfield, 1971), and (c) provided informed consent to research conditions specified by the Research Ethics Committee of National Taiwan Normal University.

2.2. Golf putting task

The putting task was measured on a physical putting green consisting of a start zone (100 cm length \times 90 cm width), a green (600 cm length \times 90 cm width), and a standard-size golf hole with a diameter of 10.8 cm. The distance between the starting point of the ball and the hole was consistent with that specified by Arns, Kleinnijenhuis, Fallahpour, and Breteler (2008). This distance was chosen to ensure that at least 50% of all putts would be missed. In addition, the motor preparation period was defined as the time between placing the putter behind the ball and initiating the backswing (Lam, Masters, & Maxwell, 2010). Event-marker data was initiated via an infrared sensor that detected the movement of the back swing during each trial. In addition, participants used their own putters. Furthermore, the experimenter judged putting performance by using a measuring tape to measure the distance between the ball and the hole on the green. A ball put into the hole was registered as a distance of 0 cm.

2.3. EEG recording

The EEG recording procedure followed that of Cheng, Huang, et al. (2015). The EEG were recorded using a stretchable electro cap (Quickcap, Neuroscan, Charlotte, NC, USA) in accordance with standards international 10–20 system (Jasper, 1958). Continuous EEG recordings were taken from 32 scalp locations using left mastoids (A1) and right mastoids (A2) as an average-ear reference offline and a FPz site of the ground electrode. In addition, vertical and horizontal electro-oculograms (VEOG and HEOG, respectively) were collected in bipolar configurations located superior and inferior to the right eye, and on the left and right orbital canthi. Moreover, all EEG data were recorded and stored using NeuroScan NuAmps acquisition amplifiers (NeuroScan, Charlotte, NC, USA) with band-pass filter. The filter was set at 1–100 Hz with the notch filter at 60-Hz during the data collection. The impedance at each electrode site was below 5 kΩ. The data was obtained at a sampling rate of 500 Hz using Neuroscan software 4.5 installed on an IBM R400 notebook.

2.4. Procedure

The participants were asked not to consume any beverages containing alcohol or caffeine for 24 h before the preliminary examination and testing day. During the preliminary examination the participants were: (a) provided with a brief tour of the testing equipment and apparatus, (b) given an explanation of the main idea of the study, (c) asked to sign the informed consent form, (d) asked to put on the Lycra electrode cap, (e) given an opportunity to engage in practice golf putting to familiarize themselves with this activity. On the testing day, participants first performed warm up trials after putting on the Lycra electrode cap. This was followed by the experimental procedure which involved a total of 60 putts in 6 separate blocks (Inter-block intervals were about 2 min). Total time taken was approximately 90 min so as to control for any fatigue effect on EEG readings (Kao et al., 2013).

2.5. Data analysis

The EEG data were analyzed offline using Neuroscan Edition 4.5 software. An EOG correction was performed to eliminate the effects of blinking following Semlitsch, Anderer, Schuster, and Presslich (1986). A band pass of 1–30 Hz with 12 db/oct FIR filter was applied to the EEG and EOG channels. Based on the work by Kao et al. (2013), 16 successful (Mean = 0 cm, SD = 0) and 16 unsuccessful putts (Mean = 46.40 cm, SD = 21.41) were selected from the available artifact-free trials. Successful trials were those that went in the hole, whereas the unsuccessful trials were defined as the 16 putts from among those that missed the hole that ended up furthest distance from the hole. For the purpose of analyzing the pre-putt electrophysiological activity in both performances, the 2 s of EEG prior to the preparation of putting were segmented into two successive 1 s sampling epochs. Trials pertaining to each 1 s epoch containing amplitudes exceeding $\pm 100 \mu\text{V}$ were eliminated from subsequent analysis (Kao et al., 2014). Furthermore, Fast Fourier transforms (FFTs) with a Hanning window were used to transform the trials into spectral power and to retain the minimum spectral leakage for artifact-free segments. Moreover, performance-related power was defined and divided into different frequencies: Mu (8–13 Hz) and SMR (12–15 Hz) following Babiloni et al. (2008) and Cheng, Huang, et al. (2015). In addition, individual alpha frequency (IAF) was performed by a standard FFT procedure (Klimesch, 1999). The IAF was defined as the frequency band showing the higher power in the 7.5–12.5 Hz spectrum. The frequency bands selected in this study were: Mu rhythm (IAF–2 to IAF + 3 Hz), SMR (IAF + 2 Hz to IAF + 5 Hz) at Cz. The mean alpha peak of the IAF was 9.9 Hz (SD = 0.8). For the statistical analysis, a logarithmic (log) transformation of the power values was used to stabilize variances across subjects (Pivik et al., 1993).

2.6. Statistical analysis

SPSS 21.0 software was used for statistical analysis. The alpha level was set at 0.05. Multivariate analyses of variance (MANOVA) for repeated measures were conducted in order to evaluate the hypotheses of the present study.

Firstly, analyses of Mu and SMR were conducted using a 2 (Performance: successful/unsuccessful performance) \times 2 (Time: T1 = –2s ~ –1s, T2 = –1s ~ 0s) at Cz repeated-measures MANOVA.

Secondly, to ensure the electrode specificity, 8–13 Hz and 12–15 Hz data were analyzed at Fz, Pz and Oz (Babiloni et al., 2008) by means of a 2 (Performance: successful/unsuccessful performance) \times 3 (Electrodes: Fz, Pz and Oz) \times 2 (Time: T1 = –2s ~ –1s, T2 = –1s ~ 0s) repeated-measures MANOVA.

Thirdly, to ensure the frequency specificity, the flanking EEG frequency bands were analyzed (Cheng, Huang et al., 2015). Repeated-measures MANOVAs were conducted in the form of a 2 (Performance: successful/unsuccessful performance) \times 2 (Time: T1 = –2s ~ –1s, T2 = –1s ~ 0s) analysis for 5–7 Hz and 16–20 Hz at Cz.

Effect size estimates were calculated using the partial η^2 statistic. In the case of a significant finding, *post hoc* analyses were conducted using paired *t*-tests, and effect sizes were calculated using Cohen's *d* (for equation, see, Dunlap, Cortina, Vaslow, & Burke, 1996).

3. Results

3.1. Mu rhythm (8–13 Hz) and SMR (12–15 Hz)

As shown in Table 1, a 2 (Performance: successful/unsuccessful performance) \times 2 (Time: T1 = –2s ~ –1s, T2 = –1s ~ 0s) repeated-measures MANOVA of Mu and SMR data revealed a significant interaction effect of performance \times time, $F(2, 38) = 5.612, p = .007$, Wilks' lambda = 0.772, $\eta_p^2 = 0.228$, power = .830. A closer look at the interaction effect indicated a significant effect for the following variables: Mu, $F(1, 39) = 5.236, p = .028, \eta_p^2 = 0.118$ and SMR, $F(1, 39) = 4.362, p = .043, \eta_p^2 = 0.101$. Post hoc analysis indicated that Mu power for successful performance at T1 was lower than that of unsuccessful performance, $t(39) = -3.215, p = .003, d = -0.25$. On the other hand there was no difference between successful and unsuccessful

Table 1

T-test results of EEG power associated with successful and unsuccessful performances.

| Time | Successful performance | | | Unsuccessful performance | | | <i>t</i> (39) | <i>p</i> |
|------|------------------------|----------|-----------|--------------------------|-----------|--------|---------------|----------|
| | EEG | <i>M</i> | <i>SD</i> | <i>M</i> | <i>SD</i> | | | |
| T1 | Fz 8–13 Hz | 1.909 | 1.415 | 1.948 | 1.351 | –.644 | .524 | |
| | Mu | 1.547 | .516 | 1.698 | .614 | –3.215 | .003 | |
| | Pz 8–13 Hz | 1.557 | .579 | 1.689 | .653 | –3.168 | .003 | |
| | Oz 8–13 Hz | 2.137 | .805 | 2.251 | .873 | –2.654 | .011 | |
| | Fz 12–15 Hz | 1.625 | .768 | 1.660 | .731 | –.393 | .696 | |
| | SMR | 1.602 | .767 | 1.603 | .697 | –.010 | .992 | |
| | Pz 12–15 Hz | 1.862 | .786 | 1.903 | .721 | –.376 | .709 | |
| | Oz 12–15 Hz | 2.560 | .842 | 2.505 | .938 | .507 | .615 | |
| | Cz 4–7 Hz | 1.963 | .382 | 1.927 | .414 | .898 | .375 | |
| | Cz 16–20 Hz | 1.381 | .725 | 1.400 | .770 | –.194 | .847 | |
| T2 | Fz 8–13 Hz | 1.546 | .884 | 1.520 | .847 | .342 | .734 | |
| | Mu | 1.285 | .545 | 1.297 | .522 | –.286 | .776 | |
| | Pz 8–13 Hz | 1.328 | .611 | 1.312 | .572 | .468 | .646 | |
| | Oz 8–13 Hz | 1.849 | .824 | 1.799 | .809 | 1.481 | .147 | |
| | Fz 12–15 Hz | 1.392 | .666 | 1.359 | .623 | .353 | .726 | |
| | SMR | 1.086 | .517 | .970 | .495 | 2.035 | .049 | |
| | Pz 12–15 Hz | 1.742 | .737 | 1.658 | .585 | .636 | .529 | |
| | Oz 12–15 Hz | 2.441 | .812 | 2.312 | .747 | 1.562 | .126 | |
| | Cz 4–7 Hz | 1.723 | .428 | 1.772 | .411 | –1.102 | .277 | |
| | Cz 16–20 Hz | .735 | .396 | .750 | .420 | –.388 | .700 | |

Note. *N* = 40. Mu = Cz 8–13 Hz; SMR = Cz 12–15 Hz; T1 = –2s ~ –1s; T2 = –1s ~ 0s. Unit: log μV^2 .

performance at T2, $t(39) = -0.286$, $p = .776$, $d = -0.02$. In addition, Mu power at T1 was found to be higher than at T2 both for successful performances, $t(39) = 4.241$, $p < .001$, $d = 0.49$ and for unsuccessful performances, $t(39) = 5.062$, $p < .001$, $d = 0.70$. In the case of SMR data, post hoc analysis indicated that power for successful performances was higher than for unsuccessful performance at T2, $t(39) = 2.035$, $p = .049$, $d = 0.23$, but there was no significant difference detected at T1, $t(39) = -0.010$, $p = .992$, $d = -0.01$. In addition, SMR power at T1 was higher than T2 both during successful, $t(39) = 4.820$, $p < .001$, $d = 0.8$, and unsuccessful performances, $t(39) = 7.336$, $p < .001$, $d = 1.00$.

3.2. Control analyses

3.2.1. Topographical specificity of sensorimotor Mu rhythm and SMR

As can be seen in Table 1, a 2 (Performance: successful/unsuccessful performance) \times 3 (Electrodes: Fz, Pz and Oz) \times 2 (Time: T1 = -2s ~ -1s, T2 = -1s ~ 0s) repeated-measures MANOVA on 8–13 Hz and 12–15 Hz data indicated a significant performance \times time interaction $F(2, 38) = 3.724$, $p = .033$, Wilks' lambda = 0.836, $\eta_p^2 = 0.164$, power = .647. Further analysis of this effect revealed a significant effect for 8–13 Hz data, $F(1, 39) = 5.928$, $p = .020$, $\eta_p^2 = 0.132$ and that Pz 8–13 Hz power data for successful performances was lower than for unsuccessful performances at T1, $t(39) = -3.168$, $p = .003$, $d = -0.20$. The similar result was found at the Oz region, $t(39) = -2.654$, $p = .011$, $d = -0.13$. No such effects were observed for the 12–15 Hz data, $F(1, 39) = 1.862$, $p = .180$, $\eta_p^2 = 0.046$.

3.2.2. Frequency specificity between successful and unsuccessful performance

We compared adjacent frequency bands during the motor preparatory period at Cz during successful and unsuccessful performances. As shown in Table 1, the 2 (Performance: successful/unsuccessful performance) \times 2 (Time: T1 = -2s ~ -1s, T2 = -1s ~ 0s) repeated-measures MANOVA on 4–7 Hz and 16–20 Hz data found no significant interaction effect of performance \times time, $F(2, 38) = 1.059$, $p = .357$, Wilks' lambda = 0.947, $\eta_p^2 = 0.053$, power = .222.

4. Discussion

The main findings of this study were that successful performances which were thought to be associated with a Type 2 state were characterized by lower Mu at T1 and higher SMR power at T2. In addition, our control analysis provided evidence of frequency specificity. Interestingly, we found that lower 8–13 Hz power during T1 for successful performances extended to the posterior cortex (Pz and Oz).

The finding of lower Mu power preceding successful performance in skilled golfers supports the research hypothesis and is consistent with previous studies. Zhuang et al. (1997) found that lower Mu power was associated with better reaction-time performance. More importantly, a causal relationship between Mu power and visuo-motor performance was reported by Ros, Munneke, Parkinson, and Gruzelier (2014) who demonstrated that reduced Mu power, produced as a result of neurofeedback training, resulted in improved serial reaction-time performance. In the context of a putting task by expert golfers, lower Mu power was associated with either a successful put (i.e., going in the hole; Cooke et al., 2014) and/or the ball coming to rest a shorter distance from the hole during a putting task, in tasks with an overall average 30% failure rate (Babiloni et al., 2008). Similarly, Cooke et al. (2015) found that lower Mu power was associated with corrective action. These findings suggest that lower Mu power is associated with greater cognitive resource allocation to response motor programming resulting in adaptive motor control in visuo-motor tasks (Lotze et al., 1999; Pfurtscheller & Lopes da Silva, 1999; Pfurtscheller, Neuper, Andrew, & Edlinger, 1997; Pfurtscheller, Neuper, & Krausz, 2000;

Sabate, Llanos, Enriquez, & Rodriguez, 2012; Sadato et al., 1998). Similarly, Bertollo et al. (2016) showed that alpha ERD was associated with a controlled performance state. This in line with the dual-process theory, which suggests that controlled processing involves the rise of self-consciousness, and the engagement of working memory and attentional control to deal with a difficult task (Barrett, Tugade, & Engle, 2004). Therefore, lower Mu power, reflecting an effective allocation of attention to core components of motor control (motor programming), may be an indicator of a Type 2 state as described in the MAP model.

The other major finding of higher SMR power preceding successful performance also supports our hypothesis and is consistent with previous studies. Higher SMR power has not only been associated with better attention-related performance, such as shortened operation duration (Ros et al., 2009) and acting performance (Gruzelier et al., 2010), but also associated with better cognitive performance, such as commission errors (Egner & Gruzelier, 2001), spatial rotation, simple, and choice reaction time (Kober et al., 2015). Higher SMR power has also been linked to better performance in elite shooters (Cheng et al., 2017). Moreover, support for a causal relationship between SMR power and visuo-motor performance is provided by Cheng, Huang, et al. (2015) who demonstrated that increased SMR power resulting from neurofeedback training resulted in improved golf putting performance. Higher SMR power has been associated with lower thalamic nucleus activity (Sterman, 1996), which, in turn, leads to less interference with somatosensory processing required for maintaining perception and attention (Kober et al., 2015; Vernon et al., 2003). Given the task difficulty (i.e., only half of the putts were successful) employed in the present study, participants needed to constantly adjust their putting actions (i.e., a controlled state). The higher SMR power preceding successful putting performances may reflect the prevention of excessive reinvestment or attention disruption and thus may be another characteristic of the Type 2 state of the MAP model.

This study demonstrated frequency specificity by showing that data from the two neighboring frequency bands (i.e., 4–7 Hz, 16–20 Hz) at Cz were not significantly different during successful and unsuccessful performances. In addition, topographical specificity analysis showed that 8–13 Hz power at Pz and Oz during T1 differed between performance outcomes, but no differences were noted at Fz. It was also found that there were no differences in 12–15 Hz power at Fz, Pz, and Oz. These findings suggested that successful performance might be modulated by the visual system (occipital areas) and dorsal visual stream (parietal areas) where visual and kinesthetic inputs converge (Touzalin-Chretien, Ehrler, & Dufour, 2010). Activation in the posterior cortex is reflected by occipital alpha power, which is associated with the processing of aim-related activities during motor preparation (Loze et al., 2001) and by parietal alpha power, which reflects specific visuospatial attention via top-down control (Romei, Gross, & Thut, 2010). Higher posterior areas activity is associated with better attention during visual performance, such as selection of a relevant object (Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999) and visual detection (Könönen & Partanen, 1993; Romei et al., 2010). These findings suggest that lower Pz and Oz alpha, reflecting an appropriate level of attention to selecting task-relevant objects, are also characteristics of the Type 2 performance state of the MAP model.

The simultaneous examination of motor control and attentional processing has shed light on the complex and dynamic cognitive mechanisms underlying the Type 2 state. Before a successful putting performance, performers exhibit lower Mu power, and lower alpha power at the Pz and Oz sites which signify the involvement of motor control and visuo-spatial selective attention. Subsequently, higher SMR power was observed before the putting initiation. Our findings provide a more detailed account of the temporal dynamics of the Type 2 state in the MAP model (Bortoli et al., 2012; Robazza et al., 2016) and controlled processing in the dual-process theory (for a review, see Furley et al., 2015), and are consistent with the updated psychomotor efficiency hypothesis (Hatfield, 2018). It is suggested that future studies include

some relevant subjective measurements, such as flow state scales (Jackson & Eklund, 2004) and self-reports of performance (Bertollo et al., 2013; di Fronso et al., 2016). It would also be useful to further examine the MAP model, especially in terms of the value of correlations between EEGs (Theta, Alpha, Mu, SMR; Babiloni et al., 2008; Cheng et al., 2017; Cooke et al., 2014; Kao et al., 2013) and participants' levels of control of the core action components of the golf putting task. Last but not least, given constraints on spatial resolution in EEG measures, consideration should be given to the use of more electrodes and the incorporation of high resolution algorithms such as surface Laplacian estimation (Babiloni et al., 2008), to provide details of cortical sources.

In summary, the Type 2 state is characterized by generally lower Mu power, and lower alpha power at Pz and Oz which reflect an effective allocation of attention to the core components of motor control and an appropriate level of attention to selecting task-relevant objects respectively, at the beginning of the preparatory process. The subsequent increase in SMR power reflects prevention of excessive reinvestment or attention disruption just before putting. These findings not only provide in-depth information regarding the cognitive processes and their temporal dynamics underlying the functional but controlled state of the MAP model, but also hint at future implications for practitioners such as neurofeedback training focusing on the studied EEG components.

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