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Higher power of sensorimotor rhythm is associated with better performance in skilled air-pistol shooters

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ABSTRACT

Objectives: Psychomotor efficiency has been linked with processing efficiency during sport performance. Reduced cortical activity in the sensorimotor area has been related to less variability in the movement preparation that is conducive to skilled motor performance. This study proposes sensorimotor rhythm (SMR), 12–15 Hz of the electroencephalography (EEG) in the sensorimotor area, may be used to investigate psychomotor efficiency in sports performance.
Method: Twenty-four skilled air pistol shooters were recruited to fire 40 shots while EEG and shooting accuracy were recorded.
Results: The data show that improved performance of skilled shooters is associated with higher SMR power during the last second and lower coherence on high alpha power at Fz-T3 before action initiation. A negative relationship is also exhibited between the SMR power and the shooting performance during the aiming.
Conclusions: This finding suggests that reduced interference from sensorimotor processing, as reflected by elevated SMR power, may be related to improved processing efficiency during the aiming period. We conclude that SMR may be used to understand psychomotor efficiency underlying air-pistol shooting performance.

Understanding cortical processes underlying optimal performance is important for improving athletic performance. Processing efficiency as posited by the neural efficiency hypothesis refers to the general state of nervous system composed with minimal neural activation in a given task (Babiloni et al., 2010, 2008; Del Percio et al., 2011). Although neural efficiency can serve as a framework for explaining the cortical processes underlying optimal performance, recent studies of skilled self-paced performance have found that more recruitment of motor programming resources in motor-related areas led to superior putting performance (Cooke et al., 2014; Ring, Cooke, Kavussanu, McIntyre, & Masters, 2015). Similarly, stronger cortical communication in the parieto-central and parieto-frontal has been found for successful putts in elite golfers (Babiloni et al., 2011). This suggests that the cortical processing in elite athletes might be more complex than that predicted solely by the “neural efficiency” hypothesis.

Psychomotor efficiency, a special case of neural efficiency, provides a more specific perspective to further understanding of the cortical processing underlying skilled self-paced performance. The psychomotor efficiency postulates less complexity in the processes associated with motor control and lower neural network activities during cognitive-motor behavior, and thus can be viewed as superior cognitive-motor processing concerning expertise (Hatfield & Hillman, 2001, pp. 362–386). Decreased cortical activation of the motor planning-related regions (e.g. sensorimotor cortex) might

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contribute to greater consistency of the motor performance (Baumeister, Reinecke, Liesen, & Weiss, 2008). The relationship between cortical activity and cognitive-motor processing can be investigated by using electroencephalography (EEG) activities in the sensorimotor region and the cortical communication between sensorimotor region and other regions. This direction of research has also been backed up by a general model for the interpretation of cortical activity associated with superior performance, the multi-action plan model (MAP model; Bertollo et al., 2016), which found that a silent sensorimotor area was associated with a more automated shooting performance in elite shooters.

Sensorimotor rhythm (SMR) is an ideal candidate for evaluating psychomotor efficiency in the EEG. SMR is a special category of EEG frequency ranging from 12 to 15 Hz observed in the sensorimotor cortex and is related to activation of this area (Sterman, 1996). Specifically, SMR power is inversely related to sensorimotor cortex activity (Sterman, 1996), indicating that lower thalamic nucleus activity is associated with less interference of somatosensory processing (Kober et al., 2015). In addition to the low and high alpha frequencies reflecting the attentional processing in general aspects and in semantic tasks, respectively (Klimesch, 1996), higher SMR power has been characterized as an adaptive state of refined task-related neural processing during psychomotor and attention-related tasks (Gruzelier, Egner, & Vernon, 2006; Gruzelier, Inoue, Smart, Steed, & Steffert, 2010; Kober et al., 2015; Ros et al., 2009).

In the context of sports, Cheng et al. (2015b) reported higher SMR power during the preparatory period in skilled dart-throwing players compared to novices. Furthermore, neurofeedback training (NFT) aimed at increasing SMR power resulted in improved golf putting performance (Cheng et al., 2015a). The beneficial effects of less variability in the movement preparation by augmented SMR NFT supports previous findings of lower cortical communication between Fz and T3 at high alpha range (Deeny, Hillman, Janelle, & Hatfield, 2003), suggesting more refined processing regarding motor execution. Taken together, we propose that SMR power is potentially sensitive to complexity during motor execution, and the effect can be compared by examining cortical communication at high alpha range as it has been considered an ideal index for assessment of inter-regional communication (Von Stein & Sarnthein, 2000). Therefore, investigating the cognitive-motor processing by using SMR power could further our understanding of psychomotor efficiency in skilled self-paced motor performance.

In this study, we used air-pistol shooting performance as the motor task because cognitive-motor processing during aiming is fundamental to skilled pistol shooting (Tremayne & Barry, 2001). Previous studies have shown that various EEG activities can distinguish successful air-pistol shooting performance from less successful performance. For example, Loze, Collins, and Holmes (2001) found that successful air-pistol shooting performance was preceded by significantly higher occipital alpha power before trigger pulls, whereas less successful performance was preceded by reduced alpha power. Similarly, Del Percio et al. (2011) found that elite air-pistol shooters were characterized by increased cortical communication within the parietal and other posterior areas, compared to non-athletes. These authors suggest that skilled shooting performance is associated with a relatively efficient manner to process visual-spatial information. However, a more relevant EEG index which can reflect cognitive-motor processing has not been investigated in air-pistol shooting performance.

The aforementioned evidence supports the functional relation of SMR power and skilled motor performance. However, the difference in regulation of psychomotor processing during motor performance between experts and novices can be assumed to be large. The SMR differences between these two highly distinctive skill categories serve as a starting point for the relevance of SMR power in skilled motor performance. In contrast, a comparison of skilled performers' performance fluctuation represents an even more sensitive test because a trial-by-trial comparison could reveal the fine-tuning of cognitive-motor adjustment in the individual (Bertollo et al., 2013; Di Fronso et al., 2016).

Therefore, our study was designed to examine different levels of SMR power during best and worst skilled air-pistol shooting performances. Based on previous findings, we expected that lower activation of the sensorimotor cortex, as reflected by higher SMR power, would be associated with better performance.

1. Methods

1.1. Participants

Twenty-four right-handed skilled shooters (14 male; 10 female) were recruited in this study, ranging in age from 14 to 22 years old (M_{age} = 18.12, SD_{age} = 2.39) with an average of 3.82 years ($SD_{experience}$ = 2.60 years) of shooting experience. They practiced shooting regularly at least four times per week. The mean shooting score of the male shooters was 557.93 and for the female shooters, 362.90. The shooters in this study were classified as B-level according to the International Sports Shooting Federation. The study was approved by an institutional review board, National Taiwan Sport University, for the protection of the human subjects. All of the participants provided their informed consent and if a participant was younger than 18 years old, a parent signed a consent form.

1.2. Air-pistol shooting task

To increase the ecological validity, this study adopted an actual shooting task in accordance with normal competitions instead of using an electrical shooting training system. A 10 m range was constructed in a purpose-built data collection building, following International Shooting Sport Federation regulations. The shooting task lasted approximately 60 min. Four 10-shot blocks were built-in and there was a 1 min break between blocks (Deeny et al., 2003). The entire shooting session consisted of 40 self-paced shots to equalize the number of shots, as the required shots in women's shooting regulations are 40. Participants used their own pistols to perform the shooting task to minimize unfamiliarity regarding pistol handling. Shot scores were determined by the terminal location on the target, which was a concentric circle in a 170 mm × 170 mm square. The bull's eye was scored as 10. The other eight concentric rings were marked with different diameters (an increase of 0.8 cm per ring) and different scores, depending on proximity to the bull's eye; a score of 9 indicated that the shot was closest to the bull's eye, and a score of 0 indicated that the shot was outside of the outermost ring but still on the target. The shot score and position for all of the participants were reported after each shot.

1.3. EEG recording

The EEGs were recorded from Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T3, C3, Cz, C4, T4, TP7, CP3, CPz, CP4, TP8, T5, P3, Pz, P4, T6, O1, Oz, and O2, corresponding to the International 10–10 system (Chatrian, Lettich, & Nelson, 1985). The left and right mastoids (A1, A2) were used as an averaged ear reference for recording and offline analyses. The ground electrode was located at Fpz. For monitoring blinks and eye movements, vertical and horizontal electrooculograms (VEOG and HEOG, respectively) were recorded located superior and inferior to the right eye and on the left and right orbital canthi. EEG and EOG signals were sampled at 500 Hz, using Neuroscan Nuamps and NeuroScan software, version 4.5