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Investigating the efficacy of neurofeedback training for expediting expertise and excellence in sport

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ABSTRACT

Objectives: This experiment examined whether electroencephalographic (EEG)-based neurofeedback could be used to train recreational golfers to regulate their brain activity, expedite skill acquisition, and promote robust performance under pressure.
Design: We adopted a mixed-multifactorial design, with group (neurofeedback, control) as a between-subjects factor, and pressure (low, high), session (pre-test, acquisition 1, acquisition 2, acquisition 3, post-test), block (putts within each training session), and epoch (cortical activity in the seconds around movement initiation) as within-subject factors.
Methods: Recreational golfers received three hours of either true (to reduce frontal EEG high-alpha power, $N = 12$) or false (control, $N = 12$) neurofeedback training sandwiched between pre-test and post-test sessions during which we collected measures of cortical activity (EEG) and putting performance under both low and high pressure conditions.
Results: Individuals in the neurofeedback group learned to reduce their frontal high-alpha power before striking putts. Despite causing this more "expert-like" pattern of cortical activity, neurofeedback training failed to selectively enhance performance, as both groups improved their putting performance similarly from the pre-test to the post-test. Finally, both groups performed robustly under pressure.
Conclusions: Performers can learn to regulate their brain activity using neurofeedback training. However, research identifying the cortical correlates of expertise is required to refine neurofeedback interventions if this training method is to expedite learning. Suggestions for future neurofeedback interventions are discussed.

Optimisation of performance is a lengthy process for novice learners who wish to become expert performers. Our goal as researchers is to develop and refine methods to shorten this training and in the process equip learners with the skills to perform under pressure. Theories of motor control contend that expert-like performance depends on accurate programming of movements during the final stages of preparation for action (e.g., Keele, 1968). These theories are supported by research that uses electroencephalography (EEG) to assess cortical activity during movement tasks (Cooke, 2013). Experts typically exhibit greater cortical specificity compared to novices when planning and executing movements, such as reduced activity in the verbal-analytic left temporal regions (e.g., Hatfield, Haufler, Hung, & Spalding, 2004). Moreover, novices show evidence of increasing cortical specificity during practice as they refine the motor skill, such as a progressive reduction in left-temporal activation (e.g., Landers et al., 1994), as they advance along the skill acquisition continuum. Building upon this evidence, it has been suggested that the acquisition of psychomotor skills might be enhanced by training individuals to emit the pattern of cortical activity associated with successful psychomotor performance (Cooke, 2013). However, the evidence to date is extremely limited. Although there are case studies of elite athletes claiming that EEG-based neurofeedback training helped them perform optimally, there are few published experiments to corroborate these claims.

The ability to acquire and master new skills quickly is crucial in many domains, including the armed forces, the emergency services,

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and sport. In order to expedite learning, some organisations employ the latest state-of-the-art brain-computer-interface systems to deliver neurofeedback training (Zaichkowsky, 2012). This technique involves teaching novice performers to produce patterns of cortical activity that characterise well-seasoned experts. The rationale for such training is that, theoretically, it speeds up learning by directly encouraging the development of neural patterns that normally take many years to evolve. However, in spite of the growing popularity of neurofeedback training in applied settings, empirical investigations of its efficacy for expediting expertise in sport are scarce. To fill this void in the existing literature, the aims of this experiment were to: a) evaluate whether neurofeedback training could teach recreational golfers to produce the patterns of brain activity characteristic of experts in the moments preceding putts; b) examine whether neurofeedback training could improve performance, thereby accelerating the evolution from novice to expert; and, c) evaluate whether neurofeedback training could help produce patterns of cortical activity and performance levels that would be robust to the potential deleterious effects of increased psychological pressure.

Neurofeedback training in sport

Neurofeedback training provides individuals with real-time information about their level of cortical activity via sounds or visual displays (Hammond, 2007). Based on principles derived from operant learning theory (e.g., Skinner, 1963), rewarding positive reinforcement, such as a change in the pitch of a tone, is provided when a desired level of cortical activity is achieved. Electroencephalography (EEG) is perhaps the most common brain imaging method that is used to provide neurofeedback training (e.g., Vernon, 2005). In brief, EEG involves the recording of electrical activity on the scalp to detect voltages generated in the brain. EEG offers exquisite temporal resolution, whereby changes in activation are detected more or less instantaneously (e.g., Harmon-Jones & Peterson, 2009). Moreover, EEG can be measured while participants stand and perform a range of movements, which makes the method particularly well suited for providing neurofeedback in sport (e.g., Thompson, Steffert, Ros, Leach, & Gruzelier, 2008).

To this end, there have been a handful of studies investigating whether EEG neurofeedback training can facilitate performance in sport, and while the evidence concerning the effectiveness of EEG neurofeedback is not conclusive, it is certainly encouraging (e.g., Arns, Kleinnijenhuis, Fallahpour, & Breteler, 2007; Kavussanu, Crews, & Gill, 1998; Landers et al., 1991; Rostami, Sadeghi, Karami, Abadi, & Salamati, 2012). For instance, the seminal study of neurofeedback in sport was conducted by Landers et al. (1991), and investigated the effects of neurofeedback in sixteen experienced archers. Landers et al. (1991) reasoned that archery performance should be associated with activation of the right-hemisphere of the brain, which is associated with visual-spatial processing, and deactivation of the left-hemisphere of the brain, which is associated with verbal-analytic processing (e.g., Hatfield, Landers, & Ray, 1984; Landers et al., 1994). Accordingly, they measured EEG activity and archery performance in pre- and post-test sessions, separated by approximately 60 min of neurofeedback training during which the archers watched their relative left- and right-hemisphere activity on a visual display. Results revealed that performance improved from the pre-test to the post-test in eight archers who were rewarded when they reduced cortical activity over their left-hemisphere. In contrast, performance deteriorated in the remaining eight archers, who were rewarded when they reduced cortical activity over their right-hemisphere.

Although this finding implies that neurofeedback training could be used to expedite learning in archery, it is important to note that left-hemisphere cortical activity in the pre- and post-test sessions was the same for members of both neurofeedback groups. This indicates that the neurofeedback training protocol did not cause members of the left-hemisphere neurofeedback group to suppress left-hemisphere function. Consequently, the improvement in performance that was achieved by this group may not be directly attributable to the neurofeedback that they received.

A more recent study of neurofeedback training by Rostami et al. (2012) also adopted a pre- and post-test design to increase the power of the sensory motor rhythm (i.e., cortical activity between 13 and 15 Hz) over central motor areas (i.e., C3 electrode site) of the brain. Specifically, twelve experienced marksmen attended 15 h of laboratory sessions spread over five weeks, and were trained to control their cortical activity by sitting and watching this activity on a screen. Results revealed that neurofeedback training led to marginal improvements in shooting accuracy from the pre-test to the post-test, whereas the performance of a control group who received no neurofeedback training was unchanged.

While this finding is also supportive of neurofeedback as a tool to aid the development of expertise and excellence in sport, the study was subject to two principal limitations. First, the choice to train participants to increase the sensory motor rhythm over central motor areas was somewhat arbitrary, with the authors providing no theoretical or empirical rationale to support this key methodological feature. Second, no measures of EEG activity were obtained during the pre- and post-test sessions. Accordingly, it was impossible to evaluate whether the beneficial effects of neurofeedback training were attributable to participants having learned to control their patterns of cortical activation.

Finally, perhaps the most informative neurofeedback study in sport was conducted by Arns et al. (2007). They adopted a crossover design in which six amateur golfers completed 12 blocks of putts. The golfers putted as normal in the odd-numbered blocks, and putted while receiving auditory neurofeedback training in the even-numbered blocks. Importantly, the element of cortical activity that was fed back to participants was partly customised to the task. Specifically, a comparison of cortical activity associated with the best (i.e., holed) and worst (i.e., missed) putts during a baseline session was conducted to customise the neurofeedback for each participant. This resulted in participants being trained to reduce a combination of theta (4–8 Hz), alpha (8–12 Hz), sensory motor rhythm (13–15 Hz) and/or beta (15–30 Hz) power in the final moments preceding putts. It is also important to note that the auditory neurofeedback tone was played to participants while they stood over the ball and prepared to execute putts. By adopting these innovative design features, Arns et al. (2007) were the first researchers to provide customised, concurrent neurofeedback training during task performance. Their results revealed that participants holed more putts during the blocks in which they received neurofeedback compared to those in which they did not.

Although this study provides arguably the strongest support for the efficacy of neurofeedback training as a tool to foster expertise and excellence in sport, it nonetheless suffers from key limitations, including low sample size and no control group. Thus, the results of the Arns et al. (2007) study may simply reflect a placebo effect whereby improved performance was elicited by the presence of the neurofeedback system and auditory tone, rather than by changes in cortical activity per se.

The cortical correlates of expertise in golf

Since the work of Arns et al. (2007), two studies have systematically examined the patterns of cortical activity that underpin successful golf putts, and the results of these studies could form the empirical grounding for new neurofeedback interventions.