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A comparison of cortico-cortical communication during air-pistol shooting in elite disabled and non-disabled shooters

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ABSTRACT

This study examined the difference in electroencephalographic (EEG) coherence, an index of cortico-cortical communication, during air pistol shooting between disabled and non-disabled elite shooters. Participants included 22 non-disabled and 12 disabled members of the Korean national air-pistol shooting team at the world class level. Electrocortical activation was recorded during 20 self-paced 10-meter air pistol shots. Higher cortico-cortical communication between brain regions was observed in disabled shooters. The higher functional communication appears to be a strategy to compensate for the attenuated function of the brain resulting from spinal cord injury. This compensatory mechanism could explain why there is no significant difference in shooting performance between elite disabled and non-disabled shooters.

1. Introduction

Shooting expertise is related to the acquisition of neural efficiency through deliberate practice. Previous studies comparing cortical activation between novice and expert shooters revealed that experts are characterized by activation of task-relevant processes, along with suppression of task-irrelevant associative activation, while novices show hyperactivity in extensive cortical areas (Deeny, Haufler, Saffer, & Hatfield, 2009; Deeny, Hillman, Janelle, & Hatfield, 2003; Haufler, Spalding, Santa Maria, & Hatfield, 2000). Deliberate practice has been reported to reduce overall cortical activation, similar to cortical processes observed in elite shooters (Kerick, Douglass, & Hatfield, 2004). Furthermore, it was demonstrated that neurofeedback training to reduce activation in a task-irrelevant cortical area facilitates performance of precision target shooting (Wang & Hung, 2006), suggesting that application of an appropriate neurofeedback training protocol could be an effective psychological skill training for peak performance of shooters. Examination on neural characteristics in expert shooters should precede the development of a shooter-oriented neurofeedback training program. Although some studies have examined cortical activation during the aiming period in elite shooters, the participants in most studies were rifle shooters whose skill level was not that of world class competitors. All these studies were aimed at shooters without disability and there is no published study to examine cortical activity in elite shooters with disability. Therefore, it is unclear if programs aimed at improving the performance of non-disabled shooting athletes could also benefit elite disabled shooters. Primary cause of disability in disabled pistol shooters is spinal cord injury (SCI). The need for comparison between the disabled and non-disabled athletes was deduced from the neural plasticity theory, which says that regeneration and reorganization occur for functional recovery after spinal cord injury (SCI) in adult humans (Levy, Amassiann, Traad, & Cadwell, 1990; Topka, Cohen, Cole, & Hallett, 1991). The reorganization processes occur in the cortical and subcortical brain areas (Rainteau & Schwab, 2001; Tran, Boord, Middleton, & Craig, 2004). More specifically, persons with SCI exhibit higher cortical activation across all brain regions relative to able-bodied controls. Furthermore, the extent of hyperactivation in brain depends on the degree of disability (Tran et al., 2004). Even under resting conditions, increased glucose metabolism was observed in SCI patients in brain areas related to movement initiation and attention (Roelcke et al., 1997). Due to the neural recovery processes, brain regions and the extent to which they are activated during motor performance may be different even if the outcome is similar between able-bodied persons and those with SCI. For this reason, a neurofeedback program developed for able-bodied shooters may induce different results in disabled shooters.

Most recently, Kim and Woo (in review) used EEG asymmetry and power spectral analysis in the high alpha band to investigate

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the interaction between disability and shooting expertise acquired through deliberate precision target shooting practice in disabled and non-disabled athletes. Consistent with a study by Tran et al. (2004), the disabled shooters exhibited hyperactivation in extensive cortical areas typically observed in patients with SCI during performance. However, in brain regions responsible for visual-spatial processing, cortical activation in disabled shooters was not different from that in non-disabled shooters. This result implies that the consistent and deliberate practice of shooting influences neural reorganization with increasing neural efficiency in shooting-relevant brain regions while maintaining hyperactivation usually associated with SCI.

Skillful target shooting requires efficient integration or orchestration of the brain areas that are responsible for visual-spatial processing, planning and control of movement. The functional communication between different areas of the brain could not be examined by measurement techniques such as event-related slow potential (Konttinen & Lyytinen, 1992; Konttinen & Lyytinen, 1993) and EEG power spectral analysis (Hatfield, Landers, & Ray, 1984; Haufler et al., 2000; Hillman, Apparies, Janelle, & Hatfield, 2000; Landers et al., 1994; Salazar et al., 1990) which have been used in previous studies. Therefore, adoption of EEG coherence analysis to investigate the functional communication between different areas of the brain is necessary to fully understand cognitive processing involved in precision target shooting.

Coherence values represent the magnitude of correlation between the respective amplitudes derived for a given frequency from two different time series (Deeny et al., 2003). High EEG coherence indicates more communication between different areas of the cerebral cortex while low coherence represents regional autonomy or independence (Silverstein, 1995; Weiss & Mueller, 2003). A comparison of coherence in expert and skilled marksmen revealed that relative to skilled marksmen, experts exhibited lower EEG coherence between the premotor (Fz), which is instrumental in motor planning and has direct cortical connections to the motor cortex, the visual cortex, and the association areas in the temporal and parietal lobes (Kaufer & Lewis, 1999), and left temporal regions (T3), which has been implicated in target shooting performance (Deeny et al., 2003). In a more recent study, experts exhibited lower coherence relative to novices, with the effect most prominent in the right hemisphere (Deeny et al., 2009). The results of these studies support the concept of refinement of cortical networks in experts. However, there are no published reports of a contrast in cortical networking between the disabled and the non-disabled during visuomotor performance. Therefore, the purpose of this study was to examine whether there is a significant difference in cortico-cortical communication between disabled and non-disabled shooters. The disabled were predicted to exhibit greater coherence estimates in most electrode sites than the non-disabled in accordance with the neural plasticity theory, which says that activation in extensive cortical areas is elevated for functional recovery after spinal cord injury. However, in brain regions responsible for visual-spatial processing, cortico-cortical communication in the disabled was expected not to be different from that in non-disabled shooters since both groups are experts acquiring shooting-related neural efficiency through deliberate practice over a long period of time. This investigation will serve as a companion report to the study by Kim and Woo (in review), which described the EEG spectral content of high alpha bands from disabled and non-disabled shooters. The findings of these studies will serve as preliminary studies for the development of a neurofeedback training program, which aims at improving performance in disabled and non-disabled elite shooters in the future.

2. Material and methods

2.1. Participants

Participants included 15 male and 7 female able-bodied (19.6 ± 1.65 years old) and 8 male and 4 female spinal cord-injured (40.8 ± 6.98 years old) members of the Korean national air-pistol shooting team at the world class level. All disabled shooters were in the SH1 class, which does not require a shooting stand to support a gun (IPC shooting, 2011). Four of the disabled were SH1A class (torso strength and function is normal) and eight were SH1B (severe impairment to lower limbs but normal function in pelvis). The number of years of shooting experience were 6.5 ± 2.1 years for the non-disabled and 8.2 ± 4.3 years for the disable. All participants were right-hand dominant (Chapman & Chapman, 1987) and ipsilateral-eye dominant. Participants currently using medication or with a history of psychiatric and neurological disorders were excluded. Written informed consent was obtained from participants prior to testing.

2.2. Materials

2.2.1. Shooting simulator

Shooting performance was measured with SCATT system (SCATT Co., Russia). SCATT system employs optical devices, which include a barrel-mounted light emitting and sensing unit and a reflective target border, which enabled the position of the instantaneous aiming point to be recorded in two-dimensional space as a function of time throughout each trial. The location of each shot was recorded as the position of the aiming point on the target at the time of the trigger pull, which was detected upon dry firing via a small microphone attached to the rifle. The location of each shot was automatically recorded and converted to shooting score with SCATT, in addition to the trajectories of the pistol on the target during the aiming period.

2.2.2. EEG

EEG data were collected and amplified by a gain of 20,000 using WEEG-32 (LXE 3232-RF, Laxtha, Korea) with a band-pass filter setting of 1–100 Hz. A 60-Hz notch filter was also employed. The sampling rate was 256 Hz samples/sec, and impedance values were maintained below 10 kΩ at all sites. The right earlobe (A2) was used as a reference and the left earlobe (A1) was also recorded to derive an averaged ear reference for reduction of lateral bias. The frontal midline site was used as a ground (Fpz). EEG data were recorded from the midfrontal (Fz), left and right frontal (F3, F4), central (C3, C4), and temporal (T3, T4) locations with scalp electrodes (stretchable lycra cap) positioned according to the International 10-20 System (Jasper, 1958).

2.3. Data preparation and signal processing

The EEG data were segmented to a 5-s window terminating with the trigger pull, corrected for baseline using the average of the interval. Each epoch was screened to exclude those in which amplitudes exceeded ± 100 μV. Epochs including artifacts and eye blinks were also excluded via visual inspection. EEG coherence on the electrode pairings of interest was calculated with software developed under Matlab 7.7 (Mathworks Inc., Natrick, MA, USA). The coherence formula and pairs of cortical areas analyzed in the present study were reported by Deeny et al. (2003), Deeny et al. (2009). Coherence was calculated in 1-Hz frequency bins and averaged across the appropriate frequencies to obtain coherence values for theta (4–7 Hz), low alpha (8–10 Hz), high alpha (11–13 Hz), beta (14–35 Hz), and gamma (36–44 Hz). All coherence estimates