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The influence of social evaluation on cerebral cortical activity and motor performance: A study of "Real-Life" competition☆

Bradley D. Hatfield [a,b,*], Michelle E. Costanzo [a,b,1], Ronald N. Goodman [a,b,2], Li-Chuan Lo [a], Hyuk Oh [a,b], Jeremy C. Rietschel [a,b,2], Mark Saffer [a,b], Trent Bradberry [b,c], Jose Contreras-Vidal [a,b,c,3], Amy Haufler [a,4]

[a] Department of Kinesiology, University of Maryland at College Park, School of Public Health, USA
[b] Neuroscience and Cognitive Sciences Program, University of Maryland at College Park, USA
[c] Graduate Program in Bioengineering, University of Maryland at College Park, USA

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ABSTRACT

Motor performance in a social evaluative environment was examined in participants (N = 19) who completed a pistol shooting task under both performance-alone (PA) and competitive (C) conditions. Electroencephalographic (EEG), autonomic, and psychoendocrine activity were recorded in addition to kinematic measures of the aiming behavior. State anxiety, heart rate, and cortisol were modestly elevated during C and accompanied by relative desynchrony of high-alpha power, increased cortico-cortical communication between motor and non-motor regions, and degradation of the fluency of aiming trajectory, but maintenance of performance outcome (i.e., score). The findings reveal that performance in a complex social-evaluative environment characterized by competition results in elevated cortical activity beyond that essentially required for motor performance that translated as less efficient motor behavior.

1. Introduction

Cognitive-motor performance is often executed within social contexts involving observation and judgment of the quality of performance as occurs in sport settings. A fundamental difference between sport and non-sport settings is the element of competition, which essentially implies a process of social comparison and explicit evaluation of performance. In essence, sport is a social-evaluative phenomenon and such competitive situations can increase the level of cognitive demand on the performer beyond that which is required simply to execute the pure motor demands of a task. The increase in such demand may explain, in part, how competition influences the quality of motor performance due to the attendant alterations of the performer's mental state and underlying neural processes. More specifically, the perception of social evaluation may manifest as an increase in cerebral cortical activation and cortico-cortical communication, relative to a non-competitive condition, and translate to the peripheral nervous system as elevated and nonessential skeletal motor unit activity. Such a change in skeletal muscle activity could then degrade the efficiency of motor performance and could negatively impact performance outcome if the changes in motor unit activity were sufficient to significantly alter the kinematics of limb movement (e.g., changing the throwing motion of the upper extremity and altering the trajectory of a pitched ball). Weinberg and Hunt (1976) examined the relationship between state anxiety and electromyographic (EMG) activity of the upper arm during a throwing motion of a ball at a target and observed an elevation in motor unit activity that was associated with heightened anxiety and degraded performance (i.e., reduced accuracy), but they did not examine concomitant brain activity. Accordingly, the present investigation adopts a social cognitive neuroscience approach, as described by Lieberman (2007), in order to understand how evaluative social settings influence the quality of neuro-motor behavior.

Investigations of brain activity (i.e., cerebral cortical dynamics) during motor performance have typically been conducted in non-competitive laboratory settings. These studies have revealed that skilled motor performance is characterized by psychomotor efficiency during task execution, relying on essential brain networks in an adaptive manner with refinement or suppression of non-essential input to the motor planning region (Deeny et al., 2003, 2009; Hatfield et al., 2004; Hatfield and Hillman, 2001). It is reasonable that such refinement of neural communication facilitates skeletal muscle coordination and congruency between the intended or planned and the actual or executed cognitive-motor action (Baumeister et al., 2008; Del Percio et al., 2007; Hatfield et al., 2004; Hatfield and Hillman, 2001). However, competition would likely perturb these brain processes to some degree depending on the perceived importance of the event. In this manner, elevated cortical activity from the

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* Corresponding author at: Department of Kinesiology, School of Public Health, University of Maryland College Park, MD 20742. Tel.: +1 301 405 2450.
E-mail address: bhatfiel@umd.edu (B.D. Hatfield).
[1] Now with the Uniformed Services University, Bethesda, MD.
[2] Now with Veteran's Administration, Baltimore, MD.
[3] Now with Department of Electrical and Computing Engineering, University of Houston.
[4] Now with Johns Hopkins Applied Physics Laboratory, Laurel, MD.

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perception of evaluation and social judgment (i.e., beyond that required for motor behavior) would promote non-essential cortical activity resulting in a discordance between intended and executed movements depending on the magnitude of non-essential brain activity.

Precision aiming tasks such as pistol and rifle shooting have been effectively employed to explore the notion of psychomotor efficiency during motor performance, since aiming requires visual-spatial processing, planning, and precise control of the extremities to avoid unnecessary movement (Deeny et al., 2009; Del Percio et al., 2009a; Hatfield et al., 2004). Such tasks hold the advantage of ecological validity relative to novel tasks employed in laboratory settings since the participants in many of these studies (e.g., individuals with varying shooting experience) are challenged with a familiar activity with which they are highly practiced and which they perform while motionless, allowing for minimal artifacts during psychophysiological recording.

Numerous studies employing electroencephalography (EEG) have revealed heightened alpha power in experts across the entire topography of the scalp during the aiming period of target shooting up to the time of the trigger pull indicative of a widespread reduction in cerebral cortical activity. However, the elevation in alpha power is often pronounced in those recording sites over the left temporal region (T3) (Hatfield et al., 1984; Haufler et al., 2000; Kerick et al., 2001; Lawton et al., 1998), which suggests attenuation of verbal–analytical processes during performance. EEG alpha power is also progressively elevated as a function of practice sessions completed over time to improve motor skill (Kerick et al., 2004). In this manner, EEG alpha power is positively related to cortical relaxation, suggesting attenuation of non-essential explicit processes during performance of a motor task and refinement and economy of neural processes while engaged with task-specific demands (Babiloni et al., 2008, 2009, 2010; Del Percio et al., 2008, 2009a,b, 2010; Zhu et al., 2011). The brain dynamics observed in the left temporal region suggest that skilled performers employ less verbal–analytical processing during the aiming period (possibly due to a shift to reliance on subcortical structures and relative engagement of right hemispheric visual-spatial processing) (Hatfield and Brody, 2000; Hatfield et al., 1984; Kerick et al., 2004). This assertion is based on the findings that superior performers exhibit relative synchrony of alpha power (relaxation) in this region compared to other cortical areas (Hatfield et al., 2004) and the convincing evidence provided by Sperry (1974), as well as Springer and Deutsch (1998), that the left temporal region is involved in verbal–analytical processing. Furthermore, the broad EEG alpha band is composed of specific ranges for low-alpha power (8–10 Hz) and high-alpha power (10–13 Hz), which are indicative of general cortical arousal and task-specific cortical arousal, respectively (Pfurtscheller and Lopes da Silva, 1999). Power is inversely related to these neural processes such that elevated low-alpha power is indicative of a reduction in general cortical arousal and elevated high-alpha power is indicative of a reduction in task-relevant attentional processes. Accordingly, the demands of competition may result in desynchrony of neuronal activity and reductions in low- and high-alpha power indicative of increased cortical arousal and heightened attentional processes.

The neural efficiency of skilled motor performance can also be assessed via EEG coherence, an EEG-derived metric, which is indicative of cortico-cortical communication or networking. A special case of neural efficiency involving the refinement of non-motor input to the motor planning region during performance was described by Hatfield and Hillman (2001) as psychomotor efficiency, a cortical state indicative of superior cognitive motor performance during which communication between various areas of the cortex and the motor planning region (i.e., the latter is assessed by recording from site Fz that overlies the mid-frontal cortex) is lower in those who are skilled at a particular cognitive-motor behavior compared to those who are relatively unskilled. Lower cortico-cortical communication or networking between non-motor and motor regions, as reported by Deeny et al. (2003), was specifically noted between the left temporal region (site T3) and the mid-frontal region (Fz) in marksmen with competitive shooting experience relative to those with an absence of competitive experience during the aiming period prior to trigger pull. More generally, Deeny et al. (2009) also noted lower coherence between broad regions cortical activity across the scalp topography and the frontal regions in expert marksmen relative to novices during the aiming period of target shooting. Collectively, the findings suggest that superior visuo-motor performance is associated with attenuation or refinement of non-essential input to the motor regions of the brain.

However, as stated above, a competitive environment may perturb the cerebral cortical activity associated with skilled performance through promotion of heightened regional activation and excessive cortico-cortical communication, which may negatively impact the brain processes essentially related to motor behavior. If practice and a focused effort to improve shooting performance results in attenuation of cerebral cortical activity, then it follows logically that a more complex and cognitively demanding environment involving social comparison (i.e., competition) would promote heightened activation and networking of cerebral cortical activity. In this manner, the neural efficiency of skilled motor performance reported by Del Percio et al. (2009b) would become disrupted during competition leading to behavioral changes in task performance. That is, degradation of motor behavior would occur in the form of non-essential limb movement owing to elevated central drive and excessive motor unit activity.

It remains to be seen whether an elevation in cerebral cortical activity is promoted by competition-induced social evaluation as no one, to date, has manipulated the social environment via direct competition to assess this possibility. If the possibility is supported, then alterations in motor performance may be caused by the processing of social demand during competition adding non-essential cortical activity and extraneous input to central motor preparatory processes beyond those required to meet the pure motor demands of a task. In this manner, the introduction of non-essential cortical activity would translate to the quality of motor behavior through an introduction of additional activation of the muscle activity of peripheral effectors (e.g., upper and lower extremities) and degradation of stability in the aiming posture and performance accuracy.

Therefore, the present study was conducted to examine concomitant changes in cortical dynamics and motor behavior associated with competition. To achieve this end, participants engaged in a precision aiming task (i.e., target shooting) during which they performed both alone and under the condition of ‘head-to-head’ competition involving direct comparison of their performance to that of an actual competitor. The social perception and evaluation associated with competition was expected to elevate cerebral cortical activity and introduce heightened cortico-cortical communication between non-motor and motor regions as revealed by EEG spectral and coherence analyses, respectively. More specifically, both low- and high-alpha EEG power were expected to decrease during competition compared to that observed during the aiming period of a non-competitive condition while EEG coherence was expected to increase during competition. In addition, the increase in regional activity and communication to the motor planning region during competition was expected to be elevated in the left temporal region relative to all other regions, indicative of excessive “self-talk” during the mental stress of the competitive condition. As such, the magnitude of reduction in low-and high-alpha power at T3 and the magnitude of elevation in coherence between sites T3 and Fz due to competition were expected to be highest compared to all other sites. Finally, relative to the non-competitive condition, the elevation in cortical activity was expected to reduce steadiness in the aiming behavior and accuracy of shot placement on the target.

2. Methods

2.1. Participants

Nineteen participants (N = 19, 2 female) were enrolled from the Reserve Officers' Training Corps (ROTC) program located at the University