Biological Psychology 105 (2015) 95–105

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Motor skill failure or flow-experience? Functional brain asymmetry and brain connectivity in elite and amateur table tennis players

Sebastian Wolf[a,*,1], Ellen Brölz[c], Philipp M. Keune[d,e], Benjamin Wesa[b], Martin Hautzinger[a], Niels Birbaumer[b,f,g], Ute Strehl[b]

[a] Institute of Clinical Psychology and Psychotherapy, University of Tuebingen, Schleichstr. 4, Tuebingen, 72076, Germany
[b] Institute of Medical Psychology and Behavioral Neurobiology, University Tuebingen, Germany
[c] Department of Internal Medicine VI: Psychosomatic Medicine, University Hospital Tuebingen, Germany
[d] Klinikum Bayreuth, Department of Neurology, Bayreuth, Germany
[e] Otto-Friedrich-University, Department of Physiological Psychology, Bamberg, Germany
[f] Ospedale San Camillo, IRCCS, Istituto di Ricovero e Cura a Carattere Scientifico, Venice, Italy
[g] German Center for Diabetes Research (DZD e.V.), University Tuebingen, Germany

ARTICLE INFO

Article history:
Received 23 September 2014
Received in revised form 12 January 2015
Accepted 12 January 2015
Available online 20 January 2015

Keywords:
Elite athletes
Table tennis
EEG
Functional brain asymmetry
Theta coherence
Flow-experience
Psycho-motor performance

ABSTRACT

Functional hemispheric asymmetry is assumed to constitute one underlying neurophysiological mechanism of flow-experience and skilled psycho-motor performance in table tennis athletes. We hypothesized that when initiating motor execution during motor imagery, elite table tennis players show higher right- than left-hemispheric temporal activity and stronger right temporal-premotor than left temporal-premotor theta coherence compared to amateurs. We additionally investigated, whether less pronounced left temporal cortical activity is associated with more world rank points and more flow-experience. To this aim, electroencephalographic data were recorded in 14 experts and 15 amateur table tennis players. Subjects watched videos of an opponent serving a ball and were instructed to imagine themselves responding with a specific table tennis stroke. Alpha asymmetry scores were calculated by subtracting left from right hemispheric 8–13 Hz alpha power. 4–7 Hz theta coherence was calculated between temporal (T3/T4) and premotor (Fz) cortex. Experts showed a significantly stronger shift towards lower relative left-temporal brain activity compared to amateurs and a significantly stronger right temporal-premotor coherence than amateurs. The shift towards lower relative left-temporal brain activity in experts was associated with more flow-experience and lower relative left temporal activity was correlated with more world rank points. The present findings suggest that skilled psycho-motor performance in elite table tennis players reflect less desynchronized brain activity at the left hemisphere and more coherent brain activity between fronto-temporal and premotor oscillations at the right hemisphere. This pattern probably reflect less interference of irrelevant communication of verbal–analytical with motor-control mechanisms which implies flow-experience and predict world rank in experts.

1. Introduction

Motor efficiency determines athletic skills characterized by automaticity, efficiency and accuracy (Yarrow, Brown, & Krakauer, 2009). The ability to direct and sustain attention to sport-relevant cues is a crucial factor in this process. Being able to focus on the task is one of the key features of the flow-experience, which can be seen as a rewarding, positive and balanced subjective experience that occurs especially in challenging situations, in which athletes follow clear goals and perceive a match between their abilities and task demands (Csikszentmihalyi, 1975). Flow comprises of the following characteristics: high but effortless attention, a feeling of being absorbed, decreased awareness of self and social evaluation (decreased self-referencing processes) and a sense of control over oneself and the outcome of the activity (Csikszentmihalyi, 2000; Csikszentmihaly & Hunter, 2003; Csikszentmihalyi & LeFevre, 1989; Moran, 2012). Perceived mental pressure during competitions can disrupt flow-experiences and may lead to anxiety, self-focus and analytical thoughts about own movements or the

* Corresponding author. Tel.: +49 0 7071 2977181.
E-mail address: sebastian.wolf@uni-tuebingen.de (S. Wolf).

[1] This work is part of the Ph.D. thesis of Sebastian Wolf that has been published in German 2013 online at the publication server of the University of Tuebingen (TOBIAS-lib)

http://dx.doi.org/10.1016/j.biopsycho.2015.01.007

outcome of the competition. In turn, motor processes may be affected by a decline in flow, causing a decline in performance. This phenomenon has been intensively studied and is called "choking under pressure" (Baumeister, 1984; Beilock & Carr, 2001; Beilock, Kulp, Holt, & Carr, 2004; Liao & Masters, 2002; Schucker, Hagemann, & Strauss, 2013; Singer, 2002).

1.1. Flow-experience or choking? Potential electroencephalographic (EEG) correlates

We are not aware of any study assessing electroencephalographic (EEG) correlates of flow-experience in athletes. However, studies in an athletic context showed increased EEG alpha power in the left hemisphere (LH), mainly over temporal areas, compared to the right hemisphere (RH) in the end of the preparatory period of a voluntary motor action in shooters, archers and golfers (Bird, 1987; Hillman, Apparies, Janelle, & Hatfield, 2000; Janelle et al., 2000; Kerick, Iso-Ahola, & Hatfield, 2000; Loze, Collins, & Holmes, 2001; Salazar et al., 1990). Crews and Landers (1993) found a right-hemispheric decrease in temporal (T4) as well as a left-hemispheric increase in central (C3) alpha power prior to a putt in expert golfers. Haufler et al. (2000) reported greater alpha power in the LH in expert compared to novice marksmen and no difference in the RH. Analysis of changes in EEG spectral power before and after practice showed an increase of left-hemispheric (T3) alpha power, associated with better shooting (Landers et al., 1994) and visuomotor performance in right-handed golfers (Kerick, Douglass, & Hatfield, 2004). Deeny and colleagues (Deeny, Hillman, Janelle, & Hatfield, 2003) observed less EEG low alpha coherence during the preparatory period of rifle shooting between the left temporal (T3) and the premotor cortex (Fz) in experts compared to less skilled shooters. According to Zhu and coworkers implicit compared to explicit motor learning is associated with less high alpha coherence between left temporal (T3) and premotor cortex (Fz) and those subjects that were provided with explicit motor learning displayed more T3-Fz coherence during golf putting after performance pressure induction (Zhu, Poolton, Wilson, Maxwell, & Masters, 2011). In sum, states of highly focused attention in the athletic contexts, which is one key feature of flow-experience, could be linked to stronger relative left-hemispheric alpha power, particular derived from temporal electrodes. Further, coherence between left temporal and premotor cortex is stronger under mental pressure and more pronounced in amateurs compared to experts. Thus, functional temporal brain asymmetry and cortico-cortical communication between the temporal and the premotor cortex could be particularly relevant for motor efficiency and flow-experience in athletes. Indeed, there are widespread anatomical connections between the premotor cortex and the motor, temporal and parietal cortex (Friederici & Gierhan, 2013; Kaufer & Lewis, 1999). In the context of psychomotor tasks and motor skill learning, these connections most probably reflect motor planning and somatosensory and visuo-motor integration (Hanakawa, 2011; Hardwick, Rottschy, Miall, & Eickhoff, 2013; Ledberg, Bressler, Ding, Coppola, & Nakamura, 2007).

1.2. Cognitive mechanisms of flow: inhibition of irrelevant cognitive processes

Increased power in the 8–13 Hz alpha frequency band is commonly regarded as an indicator of decreased cortical activity (Allen, Coan, & Nazarian, 2004). An increase in 8–13 Hz alpha power during cognitive or attention tasks is often observed over task-irrelevant cortical regions and is linked to intra-cortical inhibition (Klimesch, 1999, 2011, 2012). The observation of elevated relative left-hemispheric alpha power in temporal areas may thus imply inhibition of left hemispheric cognitive processes. As the left hemisphere is strongly associated with verbal–analytical processes, particularly in temporal areas (D'Esposito et al., 1998; Galin & Ornstein, 1972; Hellige, 1990; Kinsbourne, 1982; Springer & Deutsch, 1998), these hemispheric differences prior to the execution of a skilled sport-specific movement may indicate a reduction of self-instructions and disturbing thoughts, which are key features of flow-experience (Csikszentmihalyi & LeFevre, 1989). Left-hemispheric, verbal–analytical processes seem to be predominantly involved during early stages of skill acquisition (Springer & Deutsch, 1998) and show a decrease after skill learning (Kerick et al., 2004). This pattern is supported by the skill acquisition model of Fitts and Posner (Fitts & Posner, 1967), which states that skilled motor performance is automatic and no longer under conscious and explicit control. Further, enhanced brain activity in the right hemisphere is associated with skilled performance which could be due to superior visuo-spatial attentional skills (Hatfield, Landers, & Ray, 1984; Landers et al., 1991; Salazar et al., 1990).

Under performance pressure however, skilled athletes might redirect their attention to the outcome of a tournament or to the execution of well-known automatic skills in order to consciously regulate their movements. This attentional shift towards one's own movements has been shown to lead to motor disruptions and errors and thus to a decline in performance (Baumeister, 1984; Beilock & Carr, 2001; Gucciardi & Dimmock, 2008; Hillman et al., 2000) and seems to be linked to increased cortico-cortical communication between left-hemispheric (T3) and premotor regions (Fz) (Zhu et al., 2011). This seems to be especially prevalent in amateur compared to expert athletes (Deeny et al., 2003). Elite athletes seem to reduce the interference of irrelevant communication between verbal–analytical and motor-control areas and in this way achieve psycho-motor efficiency (Hatfield, Haufler, Hung, & Spalding, 2004). Thus, optimal psycho-motor performance implies suppression of irrelevant cognitive processes (self-reference, motor monitoring, disturbing thoughts), and enhanced exterior attention, which are key phenomena of the flow-experience.

1.3. Complementary notions of alpha asymmetry in flow: the approach–withdrawal model

In addition to the assumption that distracting verbal analytic processes are reduced during the experience of flow and that increased relative left-hemispheric alpha power may represent a correlate of this process, further alternative explanations may be derived from established models of EEG alpha asymmetry. According to the approach–withdrawal model, stronger relative right-hemispheric alpha power, specifically in anterior regions, is associated with behavioral approach dispositions, whereas the opposite pattern is associated with tendencies of withdrawal (Coan & Allen, 2004; Davidson, 2004; Harmon-Jones, Gable, & Peterson, 2010). In support of this model, approach behavior such as aggression has been shown to be associated with stronger relative right-hemispheric alpha power (Harmon-Jones et al., 2010; Keune et al., 2012). Frontal alpha asymmetry, indicative of approach motivation, might be supportive of adaptive performance in an athletic context. Nevertheless, notions of the approach–withdrawal model have not been examined in an athletic context.

1.4. Purpose of the current work

Less distracting verbal analytical processes and associated stronger relative left-hemispheric alpha power and lower coherence between left temporal and premotor cortex during motor-attention performance have received support in various studies (see Section 1.2). Thus, optimal psycho-motor performance in athletes implies suppression of irrelevant cognitive processes (self-reference, motor monitoring, disturbing thoughts), and enhanced