International Journal of Psychophysiology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Psychophysiology

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

# Shooting under cardiovascular load: Electroencephalographic activity in preparation for biathlon shooting

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ARTICLE INFO

*Article history:*
Received 19 March 2016
Received in revised form 6 September 2016
Accepted 8 September 2016
Available online xxxx

*Keywords:*
EEG
Frontal-midline theta
Alpha
Cardiovascular exercise
Biathlon shooting

ABSTRACT

This study explored the influence of sub-maximal cardiovascular load on electroencephalographic (EEG) activity preceding biathlon shooting. Frontal-midline theta and alpha power were examined to assess monitoring processes and cortical inhibition, respectively. Thirteen experienced biathletes (mean age: 17 years; 5 males, 8 females) fired sets of five consecutive shots from the standing position at a 50-meter-distant target, under two fixed-order conditions: (i) at rest and (ii) immediately after 3-minute exercise on a bicycle ergometer at 90% of maximum heart rate (HR). HR and rate of physical exertion (RPE) were measured as manipulation checks. Shooting accuracy was assessed in target rings for each shot. Frontal-midline theta and alpha power were computed in the last second preceding each shot from average-reference 61-channel EEG and inter-individual differences were minimized through a median-scaled log transformation (*Appendix*). HR and RPE increased under cardiovascular load, however, shooting accuracy did not change. Pre-shooting frontal-midline theta power decreased, whereas alpha power increased over temporal and occipital – but not central – regions. These changes were larger for greater HR values. Additionally, higher frontal-midline theta, lower left-central alpha, and higher left-temporal alpha power were associated with more accurate shooting. These findings suggest that monitoring processes are beneficial to shooting performance but can be impaired by sub-maximal cardiovascular load. Greater inhibition of movement-irrelevant regions (temporal, occipital) and concomitant activation of movement-related regions (central) indicate that greater neural efficiency is beneficial to shooting performance and can allow trained biathletes to shoot accurately despite physically demanding conditions.



## 1. Introduction

Research in precision sports (e.g., gun shooting, archery, golf putting) has provided compelling evidence that electroencephalographic (EEG) activity in preparation for action can distinguish experts from novices and best from worst performance (for review see Cooke, 2013; Hatfield et al., 2004; Lawton et al., 1998). However, while to date most research has focused primarily on performance at rest, in many sports athletes are often required to perform under conditions of intense cardiovascular load. Accordingly, the present study examined preparation for shooting in biathlon, a winter sport that combines cross-country skiing and rifle shooting.

In a typical biathlon race, two to four sets of five consecutive shots are fired at stationary targets placed at a distance of 50 m from the firing line, either from the standing or the prone position. Each shooting set is preceded and followed by a cross-country skiing lap of 2.5 to 5 km, during which elite biathletes ski at an average of 85–90% of their maximum heart rate (HR), which represents a sub-maximal intensity (Hoffman and Street, 1992). A penalty lap or penalty time is given for each target missed and the athlete with the overall fastest time wins the race. In other words, successful performance depends on the trade-off between shooting accurately and shooting and skiing fast. Two studies have examined the effects of different levels of cardiovascular load on shooting performance (Hoffman et al., 1992; Vickers and Williams, 2007). Both studies confirmed the negative effects of maximal cardiovascular load on the number of target hits – particularly, when shots are fired from the standing position. However, there is no consensus in regards to the effects of sub-maximal load typically observed during biathlon races. On the one hand, Hoffman et al. (1992) found that sub-maximal load (150 bpm) significantly decreased the number of target hits, whereas, on the other hand, Vickers and Williams (2007) found that sub-maximal load (85% of maximum oxygen uptake) did not affect the number of target hits. While these two studies were conducted on a similar population (national teams) and used the same type of physical exercise (bicycle ergometry), it has to be noted that they were published 15 years apart. During this time biathlon scores have improved considerably (http://biathlonresults.com), hinting at the fact that

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http://dx.doi.org/10.1016/j.ijpsycho.2016.09.004
0167-8760/© 2016 Published by Elsevier B.V.

modern biathletes, who deliberately train to maximize both shooting accuracy and skiing speed, may adopt compensatory strategies to maintain a proficient shooting accuracy despite the physically demanding conditions. With the aim to shed some light on the neurophysiological adaptations related to these strategies, we examined EEG activity in preparation for biathlon shooting.

Foremost, precision shooting requires that the barrel of the rifle is firmly aligned with the target at the moment of shooting (Ihalainen et al., 2015; Sattlecker et al., 2014). It is plausible to assume that this alignment has to be effectively monitored for the required aiming adjustments to be made. Monitoring processes in the cerebral cortex are primarily associated with the activity of the prefrontal region and can be quantified through examination of frontal-midline theta oscillations (around 4–7 Hz) (for review see Cavanagh and Frank, 2014). A study by Doppelmayr et al. (2008) confirmed the putative link between pre-shooting frontal-midline theta and rifle shooting performance. This study revealed that frontal-midline theta power was higher for expert marksmen than novices in the last second preceding shooting and that it increased consistently within the 3 s preceding shooting for experts, whereas fluctuated inconsistently for novices. Second, but not less important, successful performance requires that irrelevant cognitive processes are inhibited while relevant cognitive processes are enhanced (Hatfield and Hillman, 2001). Cortical oscillations in the alpha frequency (around 8–12 Hz) are attributed an inhibitory function (Klimesch et al., 2007) and, when examined concomitantly in several regions, can reveal the gating of resources away from regions with relative high alpha power towards regions with lower relative alpha power (Jensen and Mazaheri, 2010). Accordingly, cognitive processes related to regions showing high relative alpha power are inhibited, whereas those related to regions showing low relative alpha power are enhanced. Research in precision sport has found that expertise and successful performance is characterized by increased alpha power over temporal and occipital regions (e.g., Hatfield et al., 1984; Kerick et al., 2001; Loze et al., 2001) and decreased alpha power over the central regions (e.g., Babiloni et al., 2008; Cooke et al., 2014; Wolf et al., 2014).

Taken together, these findings suggest that frontal-midline theta power – as a marker of monitoring processes – and regional alpha power – as an indicator of cortical inhibition – are associated with performance and expertise in precision shooting. Intense cardiovascular exercise constitutes a potential perturbation to the relation between pre-shooting cortical activity and shooting performance. Namely, a range of peripheral and central adaptations to the increased cardiovascular load may alter frontal-midline theta power and regional alpha power in preparation for shooting. At the cortical level, the increased demands to sustain the cardiovascular exercise can cause a shift of metabolic resources away from task-irrelevant regions (e.g., prefrontal) and towards regions that are more relevant for movement (e.g., central) during the exercise (Dietrich, 2006). Greater cardiovascular activity (e.g., higher HR) would be followed by stronger shift of resources away from the prefrontal region and, therefore, monitoring processes would be impaired. At the peripheral level, increased metabolic demands call for heightened sympathetic activity and larger release of catecholamines (Obrist, 1981). In order to compensate for the greater arousal consequent to intense cardiovascular exercise, accurate shooting may require greater cortical inhibition, which could alter the balance between activation of shooting-relevant regions and suppression of shooting-irrelevant regions. Pre-shooting frontal-midline theta power and alpha power can be examined to assess the perturbation introduced by cardiovascular load.

In the present study we tested experienced youth biathletes at a shooting task at rest (no-load) and after completing sub-maximal cardiovascular exercise (load). The aims of the study were three-fold. First, to explore experienced biathletes' pre-shooting cortical adaptations to sub-maximal cardiovascular exercise. We expected that cardiovascular exercise would reduce frontal-midline theta power and increase regional alpha power over temporal and occipital regions. Second, to explore the relation between cardiovascular and neurophysiological activity when shooting under cardiovascular load. We hypothesized that greater HR – as marker of cardiovascular load – would be associated with lower frontal-midline theta power and higher alpha power over temporal and occipital regions. Third, to examine the relation between pre-shooting EEG activity and shooting accuracy. We expected that higher frontal-midline theta power, lower central alpha power and higher temporal and occipital alpha power would be associated with better shooting accuracy.

## 2. Materials and methods

### 2.1. Participants

Thirteen experienced youth biathletes (5 males, 8 females) from the Federal teams of Styria and Salzburg participated in the study. The participants were 17.08 years old ($SD = 1.66$) and reported a training and competition experience of 5 to 8 years. On average, they had a BMI of 20.72 ($SD = 1.25$) and HR-max of 200.39 bmp ($SD = 6.36$). Individual HR-max values were obtained through spiroergometry conducted within the seven months preceding testing. All participants except two were right-handed and all had normal eye sight. Participants were tested at the end of their competition season. Testing took place in an indoor range and required about 2.5 h per participant. The study protocol was approved by the local research ethics committee and all participants gave their informed consent to participate in the study.

### 2.2. Shooting task

Shots were fired from the standing position at a single, stationary 50 m distant rifle shooting target (diameter of 11.5 cm). Participants were instructed to be as accurate as possible and fire in their individual competition pace (i.e., under time pressure). Sets of five consecutive shots were fired within each of 12 blocks, i.e., 60 shots in total. Participants used their own rifle and all adopted a right-hand shooting stance (i.e., left foot in front, barrel held with the left hand, trigger pulled with the forefinger of the right hand). No feedback was given on the accuracy of each shot. Shots were detected by a microphone interfaced with the system for physiological recording through a stimulus box (StimTracker, Cedrus, CA).

### 2.3. Procedure

Following instrumentation for physiological recording, participants calibrated their rifle and practiced shooting for about 10 min. Then, they completed the shooting task under two fixed-order conditions: first without and then with additional cardiovascular load (Fig. 1). On average, the time interval between consecutive shots was 4.09 s ($SD = 0.62$) and 4.32 s ($SD = 1.09$) for the no-load and the load condition, respectively. Rest recordings (2 min sitting with eyes closed and 2 min sitting with eyes open) were conducted about 10 min before and after the completion of the shooting task.

### 2.4. Cardiovascular load

In the load condition, participants completed a bout of cardiovascular exercise at the beginning of each block, immediately before shooting. Each bout consisted in cycling for 3 min at 90% of the HR-max on an ergometer placed few steps away from the firing line (cf. Hoffman et al., 1992; Vickers and Williams, 2007). HR monitoring (chest belt, Polar Electro, Finland) confirmed that the participants exercised at the required intensity: mean HR of 182.19 bpm ($SD = 5.22$), corresponding to 90.94% ($SD = 3.14$) of HR-max. Before the first exercise bout participants warmed up by cycling at lower intensity (around 60% of HR-max).

Please cite this article as: Gallicchio, G., et al., Shooting under cardiovascular load: Electroencephalographic activity in preparation for biathlon shooting, Int. J. Psychophysiol. (2016), http://dx.doi.org/10.1016/j.ijpsycho.2016.09.004