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Brain Activity in Biathlon - A Comparison between Experts and Novices and Acute Effects of Exercise

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ABSTRACT

Background: The theta activity from frontal electrodes in electroencephalography (EEG) is discussed to originate from the anterior cingulate cortex, an important brain area for executive functions and the processing of sensory information. Several EEG-studies have linked higher frontal theta activity to more focused attention and superior performance in goal directed precision tasks. **Purpose:** The primary purpose of this study was to compare frontal theta activity between biathletes and cross-country skiers during shooting, thereby comparing frontal theta activity between experts and novices. The secondary purpose was to examine the effects of vigorous exercise on the possible differences in frontal theta activity between the groups. **Methods:** EEG frontal theta (4.01-6.2 Hertz) activity was compared between nine biathletes and eight cross-country skiers who fired 100 shots on a 5 m indoor shooting range both before and after high intensity roller skiing intervals on a treadmill. **Results:** There was a highly significant group difference in performance in both conditions ($p < 0.01$). Biathletes had on average 6% higher frontal theta activity during shooting as compared to cross-country skiers ($F_{1,15} = 4.82$, $p = 0.044$), but no significant effect of vigorous exercise on frontal theta activity in either of the two groups were found ($F_{1,15} = 0.14$, $p = 0.72$). **Conclusion:** Compared to cross-country skiers with similar endurance capacity, biathletes had significantly higher frontal theta activity during shooting. Vigorous exercise did not decrease frontal theta activity during shooting in neither biathletes nor cross-country skiers.

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To the Centre for Elite Sports Research in Trondheim (SentTIF), Department of Neuroscience, NTNU, that initiated the project in collaboration with the Institute of Sports Medicine in Paderborn, Germany. Thank you for giving me the opportunity to lead such an interesting research project.

To my main supervisor Prof. Gertjan Ettema for transferring parts of a giant pool of wisdom to a young and inexperienced master student's brain.

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ABBREVATIONS AND FREQUENTLY USED PHRASES

ACC	Anterior Cingulate Cortex
ANOVA	Analysis of Variance
AIM	The aiming period of the shot; from -2000 ms before, to trigger pull
APA	After Physical Activity, is the period of the experiment during and between roller skiing intervals
B	Biathlete
EEG	Electroencephalography
EVENT	The total epoch of the shot; from -2000 ms before, to 1000 ms after the trigger pull
G3	A skating technique, also referred to as Double Dance, which involves one double poling action for each leg push-off
Hz	Frequency
ICA	Independent Component Analysis
NOPA	No Physical Activity; the condition without exercise between shooting blocks
RPE	Rate of Perceived Exertion
SCATT	Laser Shooting System
Shooting block	Shooting blocks of 4 x 5 shots
SUB_e1-6	Sub epochs numbered from 1-6, each with a duration of 500 ms derived from EVENT, starting on -2000 ms before trigger pull
VAS	Visual Analogue Scale
XC	Cross-country skier

1. INTRODUCTION

A top athlete's ability to focus on sensory information important for task performance is one of the key elements for success in elite sports. This ability is often referred to as focused attention, and several studies have shown a relationship between higher frontal theta activity, more focused attention and better performance (Doppelmayr et al. 2008; Baumeister et al. 2008; Gevins et al. 1997) in goal directed precision tasks.

Electroencephalography (EEG) is regarded a reliable method for recording scalp potential fluctuations as a non-invasive measure of cortical oscillations from underlying neural assemblies (Gudmundsson et al. 2007). This method has been growing in popularity among sports scientists the last two decades, due to both hardware and software improvements that have minimized the contamination of the EEG-signal by artifacts and made it possible to measure EEG during human movement tasks. Theta EEG-activity in frontal electrodes was localized to the area of the anterior cingulate cortex (ACC) with synchronized functional magnetic resonance imaging and EEG (Gevins et al. 1997) and through source modelling studies (Sauseng et al. 2007; Doppelmayr et al. 2008). The ACC is part of the cingulate cortex and activity in the ACC regulates other brain areas, especially sensory areas (Posner and Rothbart 2007) and plays a crucial role in the working memory theory, on how we temporarily store, process and act on sensory information (Gevins et al. 1997; Jensen and Tesche 2002). In this concept, higher theta activity in frontal electrodes was related to higher levels of focused attention and enhanced performance in a golf study (Baumeister et al. 2008) and during rifle shooting (Haufler et al. 2000; Doppelmayr et al. 2008).

Some pioneers have shown promising results using EEG to measure brain activity during shooting (Konttinen and Lyytinen 1992). Already in 1990, Salazar and co-workers found an increase in alpha and beta activation in the left hemisphere in archers during the aiming period (Salazar et al. 1990), and the effect of EEG-feedback on performance has been investigated, also in archers (Landers et al. 1991). Concerning frontal theta activity, Doppelmayr et al. (2008) found a significantly higher frontal theta activity in experts as compared to novice shooters in the interval from -1000 to -500 ms before trigger pull. Consistently, Haufler et al. (2000) found higher frontal theta activity, during the aiming period in expert sharpshooters, compared to novices. In golfers, Baumeister et al. (2008) found higher frontal theta activity related to performance in experts, as compared to novices in that sport (Baumeister et al. 2008). The same research group also showed a significant decrease in performance accompanied by a decrease in frontal theta activity during a knee-angle reproduction task in 12 healthy male participants after exhaustive exercise (Baumeister et al. 2012). Frontal theta activity has also been shown to decrease under stress (Gartner et al. 2014). Baumeister et al. (2012) suggested that exhaustive exercise decreases the amount of attentional resources, and discussed it to either be related to central fatigue (central nervous system fatigue) or to a change in the sensory feedback from tired muscles causing higher demands for cortical processing of that feedback, which in turn lead to less focused attention.

In the Olympic sport of Biathlon, cross-country skiing and rifle shooting are combined, and depending on the discipline, the biathletes ski loops of 2,5 – 5 km with shooting between loops. According to the competition rules from the International Biathlon Union, the shooting is performed on a 50 m shooting range towards five targets with a diameter of 45 mm in prone- and 115 mm in standing-position. The rifle has to be carried on the back around the tracks and cannot weigh less than 3.5 kg (IBU 2015). The sport sets high demands for endurance capacity (Hoffman and Street 1992) and focused attention during shooting (Doppelmayr et al. 2008). The shooting task is highly complex, demanding coordination of visual input, postural balance and timing the contraction of the index finger at trigger pull (Ihalainen et al. 2015) and because of its stationary nature, thus minimizing movement artifacts, shooting in biathlon serves as a perfect goal directed precision task for EEG-research.

To the author’s knowledge, no published study has included experts and novices and examined the effect of exhaustive exercise on frontal theta activity in the same experiment. Therefore, the primary purpose of this study was to compare frontal theta activity during shooting between cross-country skiers, and biathletes, thereby comparing frontal theta activity between novices and experts. The secondary purpose was to examine if frontal theta activity decrease more in cross-country skiers than in biathletes after vigorous exercise. It was expected that frontal theta activity remained unchanged after exercise in biathletes because the situation and thus the sensory information should be familiar, whereas cross-country skiers might show further decrease in frontal theta activity, as the task difficulty increases after exercise.

The hypotheses were that; a) biathletes show higher frontal theta activity during shooting as compared to cross-country skiers with comparable endurance capacity, and b) vigorous exercise decreases frontal theta activity during shooting more among cross-country skiers as compared to biathletes.

2. METHODS

Participants

Nine biathletes and eight cross-country skiers participated in this experimental study. The characteristics of the participants are documented in table 1. The biathletes were recruited from a biathlon team in central Norway and inclusion criteria was set to at least five years of biathlon experience and two or more weekly shooting trainings. The cross-country skiers were recruited as control group as they presumably matched biathletes in physical capacity and were asked to have no specific experience with small bore rifle shooting. Before providing their written consent to participate, athletes were fully informed about the nature of the study, and that they could withdraw from the experiment at any time without giving an explanation. The study was registered at Norwegian Social Science Data Services and the Regional Committee of Medical and Health Research Ethics in Central Norway gave permission to actuate the study.

Table 1 describes the characteristics of the study participants (Mean ± SD)

	B	**XC**
Gender	7 F + 2 M	4F + 2 M
Age (years)	21 ± 2	25 ± 1
Body Mass (kg)	64.4 ± 7.5	67.9 ± 7.6
Body height (cm)	175 ± 10	177 ± 10
Biathlon Experience (years)	9 ± 2	0

B, Biathletes; XC, cross-country skiers; F, female; M, male

Overall design

The lab setting is shown in figure 2.1. The present study was a quantitative experimental study aiming to measure brain activity during shooting in biathlon. Cross-country skiers and biathletes fired 100 shots in each of two conditions: before and after high intensity roller skiing intervals on a treadmill. Data was collected between 27.11.2014 and 23.01.2015 in the middle of the competitive season.

Equipment

A 32-channel EEG-cap (QuickCap, Compumedics, USA) sampled EEG-data at 1000Hz/32 bit. A NuAmps amplifier (Compumedics Neuroscan, USA) amplified the signal and was carried in a backpack. A Scatt Laser Shooter Training System including a Scatt biathlon electronic target (Model: SBT-5) and an optical sensor (Model: OS-02), together with the Scatt Biathlon software, version 1.0.25 (Scatt Biathlon, Russia) recorded and provided instant feedback of performance, by the target turning green on successful shots. The Scatt Biathlon shooting system and the sighting of the rifle was calibrated for the 5 m shooting range using the calibration process provided by the Scatt system. The intervals were performed at 5% inclination on a 6 x 3 m motor-driven treadmill (Forcelink, Zwolle, The Netherlands). Heart rate (HR) was recorded with a Garmin Forerunner 610 (Garmin Ltd., Olathe, KS) HR-monitor. All participants used the same biathlon rifle (Anschutz Fortner sprint) that weighed approximately 3.7 kg. A Kevlar string was fastened to the loading handle of the rifle and further connected to a switch (figure 2.4), which left an electrical spark in the NuAmps amplifier, and thus synchronized the EEG-data with the shooting data. Swenor roller skis (skate) with resistance “2” wheels were used, and subjects brought their own poles, or chose the poles of their own liking from what was available in the lab (every 5 cm). An A4 sheet with a Borg scale (Borg 1970) from 6 – 20 was placed such that it was readily available for recording participants’ rate of perceived exertion (RPE). Participants were advised to wear shorts and t-shirt or similar indoor training clothes suited for performance in 18 degrees Celsius.

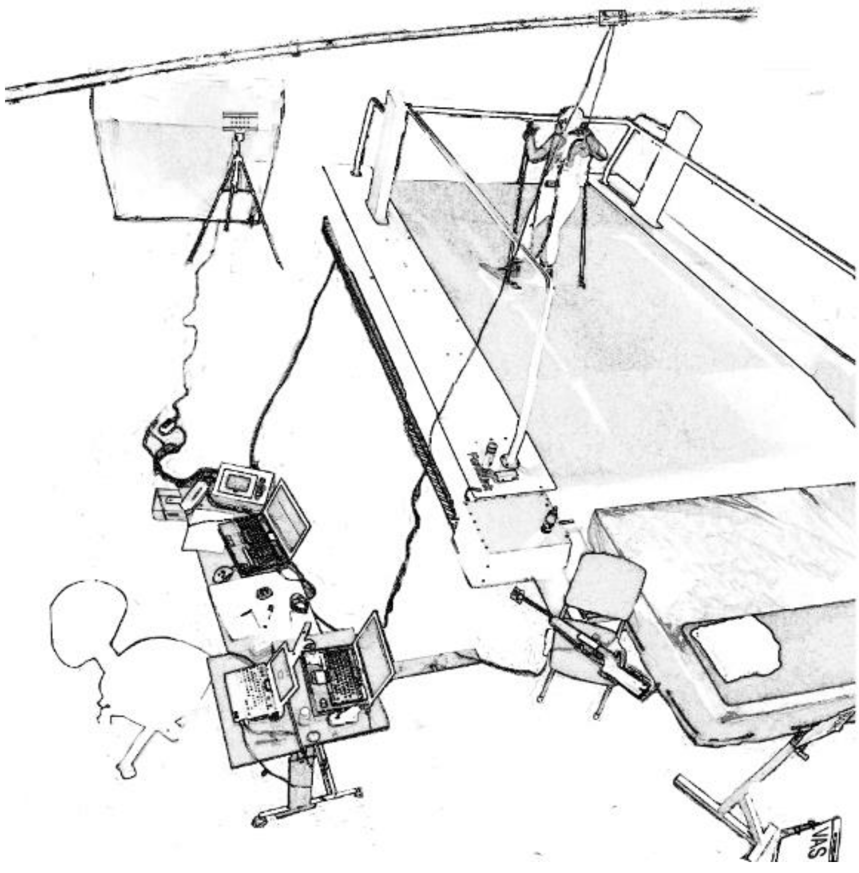

Figure 2.1 shows the lab with the large roller ski treadmill and the 5 m shooting range

Procedures

The whole protocol is presented in figure 2.3. The participants received written information about the study and had a familiarization session in the lab preceding the experiment. Cross-country skiers were taught the basics of a standing biathlon shooting position, which is displayed in figure 2.5, and all participants were instructed to shoot with both eyes open and to keep their aim for one second after the shot, to minimize EMG and movement artifacts. On the test-day the QuickCap was prepared in a calm environment outside the lab and the electrodes were placed according to the international 10:20 system (Jasper 1958). EEG was recorded continuously from 32 scalp locations (see fig. 2.6) using a mid-forehead placement of the ground electrode and linked earlobes as average reference (A1+A2/2). Resting HR measurements were done with the subjects lying supine for five minutes after preparation, to ensure stable contact with HR-monitor and the EEG-system. Participants then wore the backpack with the amplifier, picked up the rifle and stood behind a line that ensured a distance of 5 m from the target. The online EEG-signals were visually inspected when participants were standing in shooting position, and at signal from the test-leader, the participants fired 100 shots in five blocks of 4 x 5 shots and 30-second break between blocks, in a "No physical activity" (NOPA) condition. The rifle was put down during the 30-second break. Self-reported concentration level was obtained after 20 and 100 shots in both conditions on a 10 cm Visual Analogue Scale (VAS). EEG and performance in shooting were continuously measured during shooting. HR was measured before the first, and after the 20^{th} shot in each block. A black rubber flap covered the visual range of the left eye, such that the only visual information available during shooting was the sight cylinder, the front sight, the target, and the white sheet in the background (see figure 2.2).

Figure 2.2 The visual information during shooting; the target (inner black circle) turned green for successful shots

The participants were instructed to hit as many targets as possible in their own self-chosen pace, but with an extra second of aiming after trigger pull. The instructions were as standardized as possible.

The NOPA shooting was followed by a 10 min warm up while skating using a self-chosen technique on the treadmill with increasing intensity until 8 min, where participants reached 80% of their self-reported maximal heart rate (HRmax). The last two minutes of the warm up were performed at low intensity, followed by a two minutes break. The intervals consisted of 5 x 6 min skating using the G3-technique (Double Dance) at above 85% of HRmax, controlled by HR measurements at 3 min and 5:30 min during the intervals. Participants took their skis and poles off on the treadmill, stepped off the treadmill and walked to the shooting range to pick up the rifle. Twenty shots, in blocks of 4 x 5 between and after the last interval, provided 100 shots in the "after physical activity" (APA) condition. Participants had the opportunity to drink water before each interval. After every interval, subjects reported their RPE on the Borg scale (Borg 1970). All participants filled in a questionnaire after the experiment to ensure that they met the inclusion criteria.

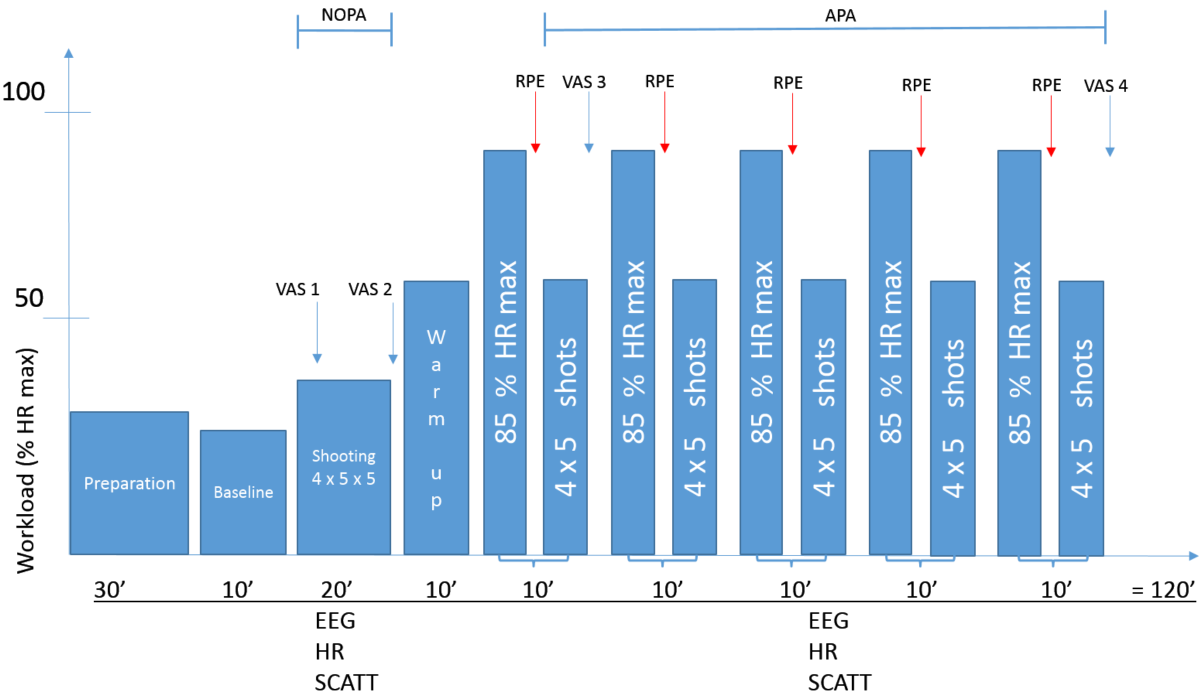

Figure 2.3 shows the protocol with workload (percent of HRmax) on the y-axis during each segment with the duration in minutes (') on the x-axis. Electroencephalography (EEG), shooting performance (SCATT) and heart rate (HR) were obtained during shooting in a "No physical activity" (NOPA) condition and "after physical activity" (APA). Self-reported concentration level (VAS) was obtained after 20 and 100 shots in both conditions. After every interval, participants reported their rate of perceived exertion (RPE) on a Borg scale

Signal processing and statistics

EEG-data was processed using the EEGlab-toolbox (Delorme and Makeig 2004) in Matlab 2013b, and epoched in the interval from -2000 ms before to 1000 ms after trigger pull (EVENT). A finite impulse response (FIR) band pass filter from 0.5 to 40 Hz removed 50 Hz line noise (Miyakoshi et al. 2013) and signals were re-referenced to the average of all electrodes. The raw signals were down-sampled to 250 Hz. An independent component analysis (ICA) removed stereotypical artifacts such as eye-blinks from the raw signals. Then an experienced electroencephalographer removed the remaining sections with artifacts. Thus, only artifact free epochs were included. Heavily contaminated channels were removed from the raw signal. The average amount of epochs after artifact rejection were 74% for the NOPA condition and 63% for the APA condition. A Fast Fourier Transform (FFT) was applied for frequency-power analysis. Sum spectral power for theta frequencies (4.01 – 6.2 Hz) in the FZ electrode was analysed and referred to as frontal theta activity. The absolute activity values (log10(μV^2), hereafter reported as μV^2) for theta frequencies in the FZ electrode were log transformed to ensure a normal distribution. One male biathlete was excluded from the analysis, and not reported in this thesis due to problems with the data collection. Statistical analyses were done in SPSS v 22.

The EVENT epoch was further divided in sub epochs named SUB_e1-6 (each of 500 ms starting on -2000 ms to -1500 ms). The average of SUB_e 1-4 will be referred to as AIM. Numbers are presented as absolute values and reported as mean and standard deviation. A two-way analysis of variance (ANOVA) for repeated measures was used to analyse factor group (cross country skiers and biathletes) and condition (NOPA and APA) and their interactions on shooting performance, and on frontal theta activity in EVENT and AIM. A two-way analysis of covariance (ANCOVA) was performed on the dependent variables AIM and SUB_e5 with condition as covariate. Group differences and condition interactions were considered as statistical significant at a *p*-value < 0.05. F-values are also given.

A two-way ANOVA was performed on the four VAS scores to control for group interactions and changes in self-reported concentration through the experiment.

Two-tailed t-tests with unequal variances assumed were performed on average HR during shooting, average HR during intervals, average speed during intervals, and average RPE to control for possible group differences in induced workload.

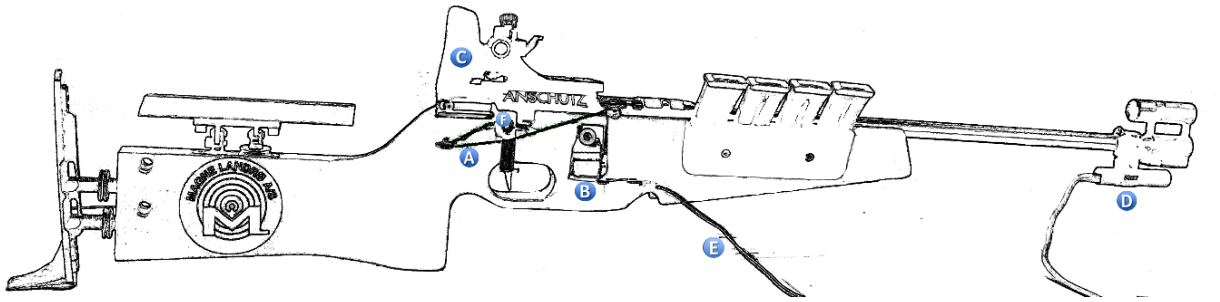

Figure 2.4 shows the mechanism that left an electrical mark in the EEG-data at trigger pull; a Kevlar string (A) connected the loading handle (F), which moved forward at trigger pull, to a switch (B) that was wired (E) and connected to the NuAmps amplifier; the figure also shows the rubber flap (C), which covered the left eye, and the Scatt optical sensor (D) at the muzzle

Figure 2.5 shows the standing shooting position with the QuickCap on, and the amplifier in a backpack

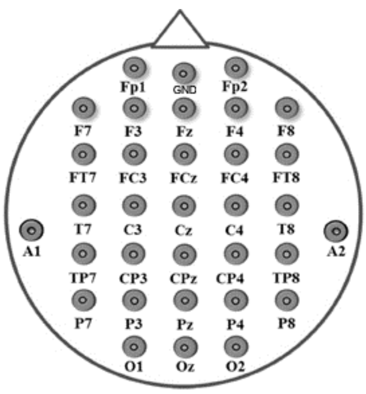

Figure 2.6 shows the 32 scalp locations with the linked earlobe electrodes (A1 + A2) and ground electrode (GND). Theta activity in the FZ electrode were analysed

3. RESULTS

Shooting performance in every block is presented in figure 3.1. Biathletes hit on average 80 ± 14% (mean + SD) and 81 ± 10%, and cross-country skiers 39 ± 13% and 44 ± 11% of the targets in NOPA and APA shooting, respectively. Thus, biathletes hit significantly more targets as compared to cross country skiers (group interaction: $F_{1,15} = 48.3$, $p < 0.01$). The intervals did not affect the shooting performance (condition interaction: $F_{1,15} = 2.20$, $p = 0.16$) nor did the intervals affect shooting performance differently among biathletes and cross-country skiers (group x condition interaction: $F_{1,15} = 1.06$, $p = 0.32$).

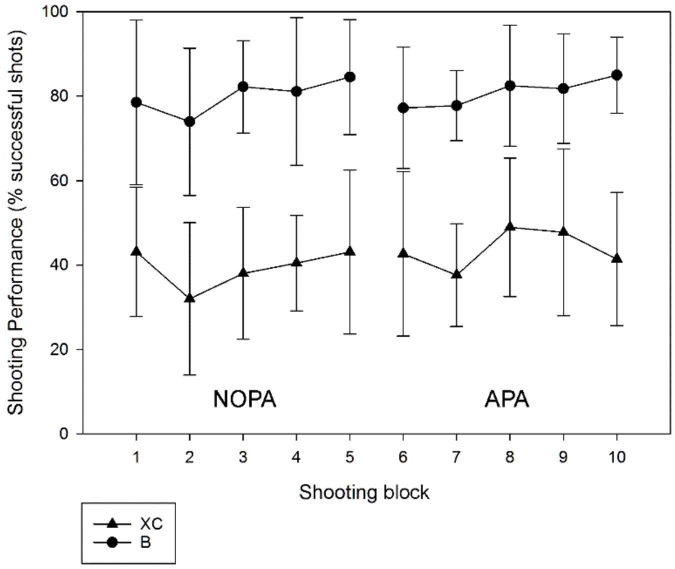

Figure 3.1 shows shooting performance in all shootings for both groups and both conditions; XC = Cross-country skiers; B = Biathletes; NOPA = No physical activity; APA = After physical activity

RPE, HR during each shooting and HR during intervals are shown in figure 3.2, 3.3 and 3.4 respectively. The VAS scores from all four VAS measurements are shown in figure 3.5. No group differences in average HR during shooting, average HR during intervals, average speed during intervals or average RPE were found. The average HR during NOPA and APA-shooting was 40 ± 5% and 63 ± 4% of HRmax in biathletes, and 40 ± 5% and 60 ± 5% of HRmax in cross-country skiers. During intervals, the average HR was 88 ± 4% in biathletes and 86 ± 4% of HRmax in cross-country skiers. The average speed during intervals was 11.2 ± 2.2 km/t for biathletes and 11.9 ± 1.3 km/t for cross-country skiers. Average RPE was 14.4 ± 0.5 in biathletes and 14.5 ± 1.0 in cross-country skiers.

There was no significant group difference in the VAS scores ($F_{1,14} = 0.19$, p = 0.67), nor did the VAS-scores develop differently among biathletes compared to cross-country skiers

($F_{3,42}$ = 2.30, p = 0.091). However, a tendency for the VAS scores to develop differently between biathletes and cross-country skiers during APA shooting (VAS 3-4) was found (group x condition interaction: $F_{1,15}$ = 4.41, p = 0.053). Average VAS score for cross-country skiers went down from 7.5 ± 1.9 cm in VAS 3 to 7.0 ± 2.0 cm in VAS 4 , but up from 6.8 ± 1.7 cm in VAS 3 to 8.4 ± 1.7 cm in VAS 4 among biathletes.

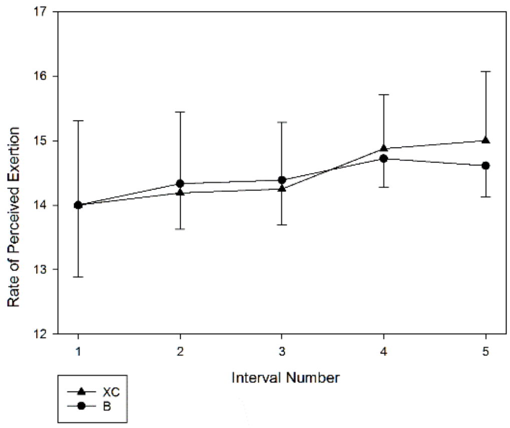

Figure 3.2 shows the average cross-country skiers' (XC) and Biathletes' (B) Rate of Perceived Exertion on a 6 - 20 Borg scale, after intervals. Intervals 1 – 5 correspond to shooting 6 – 10 in figure 3.1 and 3.3

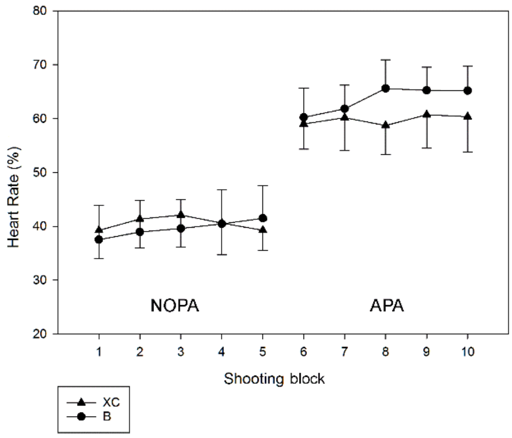

Figure 3.3 shows the average heart rate in percent of HRmax during each shooting for cross-country skiers (XC) and biathletes (B). The five first shootings in "No Physical Activity" (NOPA) and 6-10 in "After Physical Activity" (APA)

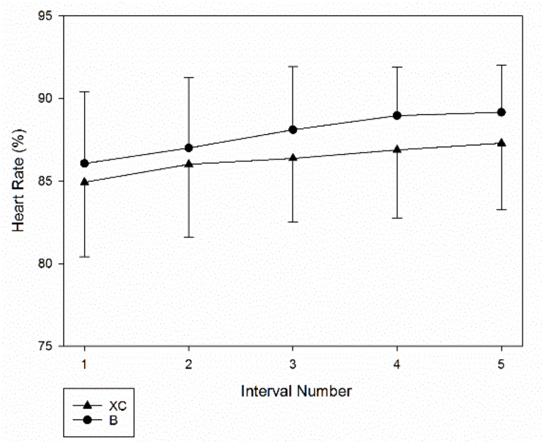

Figure 3.4 shows the average heart rate in percent of max for cross-country skiers (XC) and biathletes (B) during intervals. Interval nr. 1 corresponds to shooting nr 6 in figure 3.1 and 3.3

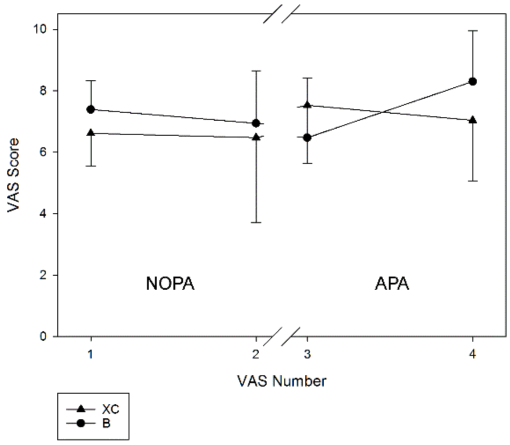

Figure 3.5 shows the average self-reported concentration level, measured at four time points (after 20 and 100 shots in both conditions) with a 10 cm visual analogue scale (VAS)

The frontal theta activity in all sub epochs in cross-country skiers and biathletes in both conditions are shown in figure 3.6. For the EVENT epoch, biathletes had on average 6% higher frontal theta activity as compared to cross-country skiers ($F_{1,15} = 4.82$, $p = 0.044$). No significant effect of condition ($F_{1,15} = 0.14$, $p = 0.72$) nor group x condition ($F_{1,15} = 0.25$, $p = 0.62$) on frontal theta activity in the EVENT were found. Average frontal theta activity during EVENT in NOPA was 17.07 ± 0.57 μV^2 in cross-country skiers, and 17.97 ± 1.14 μV^2 in biathletes. Average frontal theta activity during EVENT in APA-condition was 16.90 ± 1.01 μV^2 and 18.00 ± 1.20 μV^2 in cross country skiers and biathletes respectively.

Biathletes had on average 6% higher frontal theta activity as compared to cross-country skiers during the AIM epoch. However the average difference between the groups during AIM did not reach statistical significance ($F_{1,15} = 4.46$, $p = 0.052$). No significant effect of condition ($F_{1,15} = 0.11$, $p = 0.74$) nor for group x condition ($F_{1,15} = 0.24$, $p = 0.63$) on frontal theta activity in AIM were found. In NOPA, frontal theta activity values were 16.87 ± 0.57 μV^2 and 17.76 ± 1.14 μV^2 for cross-country skiers and biathletes respectively. In APA, frontal theta activity was 16.70 ± 1.12 μV^2 and 17.80 ± 1.22 μV^2 for cross-country skiers and biathletes respectively.

The average theta activity for both groups in SUB_e5 was significantly higher than the theta activity during AIM ($F_{1,31} = 20.45$, $p < 0.01$).

When analysing each sub epoch, biathletes had significantly higher frontal theta activity in SUB_e3 ($p = 0.049$) and SUB_e5 ($p = 0.045$) in the NOPA condition and significantly higher frontal theta activity in SUB_e5 ($p = 0.028$) in the APA-condition.

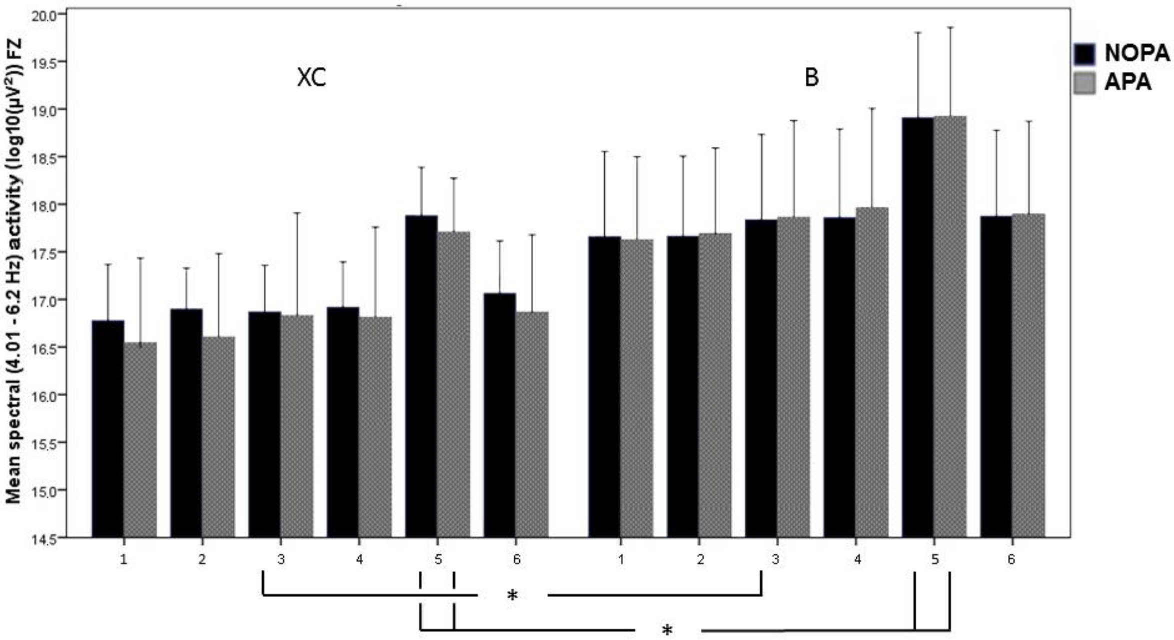

Figure 3.6 displays mean and SD of frontal (FZ electrode) theta (4.01 – 6.2 Hz) spectral activity, for both groups and in both conditions in SUB_e 1- 6, each with a duration of 500ms, starting on 1 = [-2000ms 1500ms] until 6 = [500ms 1000ms]. NOPA, no physical activity; APA, after physical activity; B, biathlete; XC, cross-country skier. * significant ($p < 0.05$) group difference in this sub epoch

4. DISCUSSION

Frontal EEG theta (4.01 – 6.2 hertz) activity during shooting in biathlon and the effects of vigorous exercise on frontal theta activity was compared between cross-country skiers and biathletes. Biathletes had higher frontal theta activity as compared to cross-country skiers for the EVENT (-2000 ms before to 1000 ms after trigger pull) and thus confirming the primary hypothesis that biathletes have higher frontal theta activity during shooting in biathlon as compared to cross-country skiers. Although data was analysed from surface EEG and the underlying neural generators are not directly measured, the higher frontal theta activity in experts are in line with previous findings where experts and novices are compared, as in the golf study by Baumeister et al. (2008) and shooting studies by Doppelmayr et al. (2008) and Haufler et al. (2000).

Vigorous exercise did not significantly affect frontal theta activity in neither biathletes nor cross-country skiers. Therefore, the results did not indicate that vigorous exercise elicits further decrease of frontal theta activity in cross-country skiers compared to biathletes, and thus the secondary hypothesis was not confirmed.

Self-reported concentration level (VAS – score), heart rate (HR) values during shooting and the rate of perceived exertion (RPE) did not change significantly within the “no-physical activity” (NOPA) and the “after-physical activity” (APA) condition. Together, the HR-values and RPE-scores indicate that both the metabolic work rate as well as the perceived exertion remained more or less constant within NOPA and APA.

Biathletes had significantly higher frontal theta activity in SUB_e3 (-1000 ms to -500 ms before trigger pull) in NOPA. Remarkably, Doppelmayr et al. (2008) found significantly higher frontal theta activity in expert sharpshooters as compared to novices, exclusively in the exact same period (-1000 to -500 ms before the shot). Doppelmayr et al. (2008) concluded that experts are superior in timing their focused attention, in that experts know not only what to focus on, but at what time they should increase their attention to certain afferent stimuli. This seems to apply also here, although there were tendencies for group differences in frontal theta activity in all sub epochs. Haufler et al. (2000) argued that lower theta activity in novice shooters could be a result of less automatization of the shooting process compared to experts, and suggested that the novice shooters direct their attention to body-position instead of performance enhancing information.

It can be speculated that the lack of an effect of vigorous exercise on frontal theta activity is due to the long time from the end of the intervals to shooting and therefore providing too long recovery time before the first shot. However, another reasonable explanation for the equal effect of vigorous exercise on frontal theta activity in the two groups, is that both biathletes and cross-country skiers compete on extreme intensities. Even if cross-country skiers do not perform precision tasks such as shooting, they have to direct their focus to technical issues related to skiing technique during competition. Future EEG-studies on biathlon should ensure a lab design that allows for a shorter and more sports specific time interval from the end of the intervals before the first shot, which was not possible with the current design. More importantly, future research aiming to investigate the effect of vigorous or exhaustive exercise on frontal theta activity in a similar setting should include physically untrained participants to compare the acute effects of exercise on frontal theta activity in expert shooters with high endurance capacity to expert shooters with lower endurance capacity.

Biathletes had significantly higher frontal theta activity in SUB_e5 (0 ms to 500 ms after the shot) in both conditions, and both biathletes and cross-country skiers had significantly higher frontal theta activity in SUB_e5 compared to frontal theta activity during AIM. This could be related to the visual feedback from the target and performance monitoring. Performance monitoring is a term used to describe cognitive functions that evaluates sensory information and determines whether adaption is needed (Ullsperger et al. 2014). According to the reinforcement learning theory (Holroyd and Coles 2002) the ACC is thought to play an important role in error processing and recruits necessary adjustments based on sensory feedback directly through cortico-cortical projections (e.g. with sensorimotor cortex or motor cortex) or indirectly through the striatum and ventral tegmental area (Ullsperger et al. 2014). The higher frontal theta activity in SUB_e5 in both groups, could indicate a focusing of attention to the visual feedback, and the significantly higher frontal theta activity in biathletes in SUB_e5 in both conditions might suggest that biathletes interpret and process the visual feedback from the target differently as compared to the cross-country skiers, but the mechanisms behind remain unknown. Therefore, future research on biathlon could benefit from investigating the impact of visual feedback from the target by comparing frontal theta activity in successful and unsuccessful shots to investigate if there is a difference in frontal theta activity between positive or negative feedback from the target.

Methodological considerations

During piloting for the present project, it was tested to run the intervals on a higher intensity than the final >85% HR max to compensate for the relatively long recovery time from intervals to shooting, but this caused too much sweat underneath the QuickCap and consequently resulted in bad signals. Cotton pads underneath or on the cap could possibly serve as a solution for future studies to cope with the problems with sweat. However, pilot testing to investigate the effect, how the cotton pads should be placed, and how the pads could interfere with signal acquisition would be needed.

Conclusion

Compared to cross-country skiers with comparable endurance capacity, biathletes had significantly higher frontal theta activity during shooting, indicating superior ability to focus on sensory information important for the shooting task in biathletes. Vigorous exercise did not affect frontal theta activity in neither biathletes nor cross-country skiers. Therefore, in contrast to what was hypothesised, vigorous exercise did not cause further decrease in frontal theta activity among cross-country skiers. This could be explained by cross-country skiers' ability to sustain high focused attention related to skiing technique during competition. However, the findings should be interpreted with care and further research is needed to clarify the underlying mechanisms.

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