Exploring the Brain Activity Related to Missing Penalty Kicks: an fNIRS Study

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Master Graduation Project by:

Max W. J. Slutter

Supervisors:

Dr. Mannes Poel, Dr. Nattapong Thammasan

and Prof. Dr. Dirk K. J. Heylen

Abstract

Despite having a near perfect control over a ball, professional football/soccer players still often miss penalties. In fact, one fifth of the penalties in professional football are missed. Psychological factors, such as anxiety or pressure, are often named as explanations for these misses. A commonly used terminology for this is 'choking under pressure'. In this study, functional near-infrared spectroscopy (fNIRS) was used to research the influence of the brain on this process. An "in the wild" study was set-up (N=22), in which each participant took 15 penalties under three different pressure conditions. Both experienced and inexperienced football players were included. Using permutation statistical tests, it could be concluded that the task-relevant brain region, the motor cortex, was more activated when players were not experiencing (performance) anxiety. The activation of task-irrelevant areas was shown to be related to players experiencing anxiety and missing penalties. These task-irrelevant areas were related to the PFC. More particularly, an overall higher activation of the PFC and an increased right as compared to left PFC activation were related to anxious players and missed penalties. The long-term thinking ability of the PFC is believed to be an explanation for this, as players might think about the consequences of scoring or missing the penalty kick. Furthermore, the results indicated that inexperienced players showed a higher left temporal cortex activation than experienced players. When experienced players were feeling anxious, their left temporal cortex activation increased and for inexperienced the opposite was observable. As the left temporal cortex is related to self-instruction and self-monitoring, this could be an indication that experienced "overthink" the situation and neglect their automated skills, whereas inexperienced players do not instruct themselves enough. Moreover, a higher connectivity between the motor cortex and the dorsolateral prefrontal cortex (DLPFC) is implied to be related to performing under pressure. Players that scored a penalty under pressure namely showed an increased in this connectivity. The results regarding the left temporal cortex and the connectivity were, however, not significant and therefore only give an indication. Overall, the results of this study are in line with the neural efficiency theory. At last, this study also shows that it is possible to get reliable results during an "in the wild" fNIRS experiment, involving physical activity.

Contents

Chapter 1

Introduction

It is the 122nd minute of the quarter final of the 2010 World Cup Football. The scores are equal and Ghana gets a penalty kick against Uruguay after a Suarez handball. Asamoah Gyan takes the responsibility. He is the best penalty kicker of the team and has already scored two penalties during that World Cup. It will be the very last kick of the game. If Gyan scored, Ghana would have gone to the semi final and be the first African country to achieve this. Gyan put the ball on the penalty spot, took a run-up and smashes the ball against the bar. The ball ended up in the crowd and the referee blew the final whistle. Ghana lost the ensuing penalty shoot-out and were eliminated from the tournament.

In theory, it should be possible to always score a penalty, since it takes less time for the ball to reach the goal than for a goalkeeper to dive to a corner. This means that in order to save a penalty the goalkeeper has to dive before the ball is kicked [1, 2]. This gives the kicker an advantage, as the goalkeeper has to make the first move. If the penalty is taken well, there is no chance for the goalkeeper to save it. Especially professional and talented football players, like Asamoah Gyan, should be able to always score a penalty. Yet penalties are often missed. Besides Gyan's miss, there are other famous examples. The penalty shoot-out between Germany and Italy in the quarter finals of the 2016 European Championship is one of them. Although the penalties were taken by some of the most talented football players in the world, 7 out of 18 penalties were missed and 4 were not even struck at goal. More recently 9 penalties in a row were missed during the 2020 Japanese Super Cup penalty shoot-out.

These examples are related to extreme cases, however also during 'regular' football matches, penalties are often missed. In Table 1.1 an overview is given of penalty statistics of the top 10 European leagues from the last 10 years. As can be seen, only 78.57% of the penalties are scored, meaning that more than one fifth of the penalties is missed.

Considering the amounts of fans and money that are involved in football nowadays, winning matches and trophies is becoming increasingly important. If Asamoah Gyan would have scored his penalty, all of Africa would have been overjoyed. After missing he left all fans disappointed. Another example: if Arjen Robben would have scored his penalty in the 2012 UEFA Champions League final, it would have earned his club a total of 19 millions euros.

Also during 'regular' league matches, the importance of penalties is high. Although in such games missing penalties has less of a direct negative emotional and financial impact, it still has a large influence on the outcome of the match. Especially given the fact that goals are scarce in football. A game namely has 2.70 goals on average (when looking at the top 10 European football leagues from 2009 to 2019)[1]. This means that each goal

League	Penalties per Game	Goals Via Penalty (%)	Penalties Scored (%)
England	0.25	6.99%	78.18%
Spain	0.28	8.01%	77.42%
Germany	0.27	7.09%	77.08%
Italy	0.32	9.21%	75.64%
France	0.26	8.45%	84.81%
Russia	0.31	9.57%	73.87%
Portugal	0.32	10.66%	86.16%
Ukraine	0.28	8.89%	78.40%
The Netherlands	0.27	6.85%	79.74%
Belgium	0.31	8.11%	74.41%
Average	0.29	8.38%	78.57%

Table 1.1: Average penalty statistics of the top 10 European leagues from 2009/2010 to 2018/2019.[1]

could be the difference between winning or losing. Out of all the goals scored, 8.38% are from the penalty spot. Furthermore, there are 0.29 penalties per match on average (see Table 1.1). This shows that a large number of goals are scored from penalties. It has also been found that scoring a penalty increases the chances of winning by 32% [3], further demonstrating the importance of penalties.

An obvious reason for missing penalties is the level of skill of the kicker and the goalkeeper. Skilled kickers have increased chances of scoring and skilled goalkeepers are more likely to save a penalty. However, it has been found that physiological factors play an even bigger role [4]. The pressure of having to score a penalty often seems to be too much, even for the most skilled and experienced players, causing them to miss. When the stakes are higher, the probability of scoring decreases [5]. Also, being more anxious has a negative influence on the quality of the penalty [6]. This phenomenon of failing to perform under pressure is also referred to as 'choking under pressure'. This explains why Gyan missed his penalty in the last minute. Although he was a very skilled individual, the pressure was too much for him. Gyan choked under pressure. The question remains why people do choke under pressure. Why do anxiety and pressure have such a big influence? Furthermore, some football players seem to be affected more by pressure than others. Where Gyan choked under pressure, other players remain calm. This raises another question: why are some players less likely to choke under pressure?

There is one part of the body that is involved in both the execution of motor skills and the processing of emotions: the human brain. Therefore the involvement of the brain during a penalty kick would be interesting to research. Although a lot of studies have been done related to factors that potentially have an influence on missed penalties, the involvement of the brain has not been extensively researched yet. And although some studies exist where the link between choking and brain activity is researched, there is a lack of experimental studies, especially in the sports domain. Regarding choking under pressure during penalty kicks, some theories exist [7], however, the number of experimental studies is low. In fact, only one study has been found where brain activity was measured during a penalty kick situation [8]. This study was not even focused on choking, instead the differences in brain activity between experts and novices were measured. Moreover, the study of Kuriyama et al. [8] was from the goalkeepers perspective. Only the brain

[1]Data obtained from: *www.transfermarkt.com*

activity of the goalkeeper was measured. Furthermore, no actual physical movement was involved in this study. Videos were namely used instead. These videos were recorded from the goalkeepers perspective, showing football players kick the ball towards the camera. Although these videos may be a close representation of a real penalty kick, they are not the same as the actual situation. Also, in other sports, no study has been found related to the link between choking and brain activity during actual execution of the sport. During a penalty kick, there is a lot of pressure in a relatively short period of time, unmatched by most other sport situations. Therefore a penalty kick is an interesting situation to research, as choking due to the pressure is likely to happen. Overall, the scarcity of experimental studies in this field of research shows the added value of this study.

Main reason for this scarcity, is the fact that movement causes significantly large artefacts in electroencephalogram (EEG) data. In EEG research, the brain activity is measured in the form of electrical activity and EEG is the most well known and most commonly used modality for neurophysiology related research. Besides EEG, one can also use functional near-infrared spectroscopy (fNIRS) to measure brain activity. Unlike EEG, this modality uses near-infrared light to measure differences in blood-oxygen levels. Similar to muscles, where oxygen levels in the blood rise when the muscle is tightened, oxygen levels rise in certain parts of the brain whenever this part of the brain is more activated. Major downside of fNIRS is its significantly lower temporal resolution compared to EEG. Therefore it is not often used, however, fNIRS excels in its robustness to motion. In fact, Carius et al. [9] showed that fNIRS is capable of reliably measuring brain activity during bouldering, a climbing sport involving complex whole-body movements. This shows that by using fNIRS, it is possible to measure brain activity during physical activity without the presence of significantly large artefacts. Furthermore, although fNIRS has lower temporal resolution, it has been used before to measure the effects of pressure on performance decrements [10]. This study was not related to physical activity, instead a working-memory task was used. Yet, it still shows that fNIRS can be used for such measurements. To conclude, fNIRS is a suitable way to reliably measure brain activity during a penalty kick, without the involvement of major artefacts such as in EEG measurements.

As previous studies have pointed out that there is a difference in the brain activity of sportsman/sportswoman with a different level of expertise [8, 11], the level of expertise is also an interesting factor to consider. Although most studies related to expertise focus on skill-level (for example, expert goalkeepers show higher activation related to anticipation than novice goalkeepers [8]), there potentially is a difference in brain activity between experts and novices during choking. It may seem evident that more experienced players are less likely to choke under pressure than novice players, as they have been in such high-pressure situations before. On the other hand, novice players may feel less pressure to score, as less is expected of them. They have less to lose. The level of expertise is therefore also an interesting factor to include. It could namely show if experience and expertise improves one's ability to deal with pressure.

To conclude, this study will focus on using fNIRS to measure brain activity during the physical execution of a penalty kick. The aim is to investigate what the relationship between certain brain activity and choking under pressure is. Furthermore, participants with a different level of expertise will be included, as it has been shown in previous studies that there is a difference between the brain activity of experts and novices. By using related work the brain regions of interest and a number of potential theories were defined. These theories were then tested in an experiment.

1.1 Motivation

As explained before, penalty kicks are highly important in football. Penalties are common (in almost one third of the matches, a penalty kick is present) and have a big influence on the outcome of a match. By also taking the large amounts of money and number of fans into account, the importance of penalty kicks increases even more. Namely, missing a penalty in a crucial match can cause thousands of fans to be disappointed and the corresponding a club to miss out on millions of euros.

As penalties have such an importance in contemporary football, numerous previous studies have looked into the causes of missed penalties (see Section 3.1). It has been shown multiple times that (external) pressure and the kicker's anxiety reduce the quality of the penalty and therefore also reduce the chances of scoring. Although the brain potentially has a large influence on this process and some theories exist [7], only one study was found where brain activity was measured in a penalty kick situation [8]. However, as explained before this study by Kuriyama et al. did not focus on choking and no actual movement was involved. Also in other sports that have something similar to a penalty kick (e.g. a penalty in hockey), no studies were found where brain activity was measured during the actual execution of a penalty. This lack of experimental studies shows the importance of this study. By measuring brain activity during the actual physical activity, one gets closer to what a real penalty is like. In other words, closer to what really happens in the brain when missing a penalty kick.

Although studies related to brain activity and stress or pressure in sports are limited, the level of expertise has often been researched. It has been shown that experts show significantly different brain activity than novices [8, 11], however, this difference in expertise is often demonstrated by skill. Experts show more efficient brain activity or activate the 'correct' areas of the brain for a certain activity when performing a skill. The relationship between expertise and dealing with pressure has been researched less extensively. Therefore, it would be interesting to see if, for example, experts are better at dealing with pressure than novices.

The findings of this study can also be of interest outside the football/sports domain. Namely, the results of this study can tell something about the relationship between motor execution and emotions in the brain. This could, for example, be useful information for surgeons who work under very high pressure. Any mistake would be crucial and information about the role of the brain in this process can be vital. This study can namely give insights on why people fail to perform under pressure and possibly also lead to finding the brain activity associated with performing under pressure.

In short, the motivation behind this study is the importance of penalty kicks in contemporary football and the lack of experimental studies regarding brain activity and penalty kicks. To our best knowledge this is the first study that measures brain activity during the actual execution of a penalty kick. Furthermore, the correlation between expertise and dealing with pressure has not been researched extensively before, especially not in a penalty kick situation. At last, the findings of this study can of interest for domains outside the football/sports domain as well.

1.2 Research Questions

Within this study, it is the aim to answer the following main research question:

RQ: What brain activity is associated with choking under pressure in a penalty kick situation?

This main research question was divided into several sub-research questions:

SubRQ1: What is the difference in brain activity between performing (scoring) and not performing (missing) when taking a penalty kick?
SubRQ2: What brain activity is associated with performing under pressure during a penalty kick situation?
SubRQ3: What is the general difference in brain activity between expert and novice football players whilst taking penalty kicks?
SubRQ4: What brain activity is associated with expert football players that experience (performance) anxiety when taking a penalty kick?
SubRQ5: What brain activity is associated with novice football players that experience (performance) anxiety when taking a penalty kick?

In order to answer these research questions, related work has been studied (see Chapter 3) and an "in the wild" experiment has been set-up (see Chapter 4). Based on the related work, a number of hypotheses were established. An experiment was done in order to test these hypotheses. In this experiment, both experienced and inexperienced football players took several penalties whilst their brain activity was measured. Within this experiment, different ways to induce pressure were implemented.

Chapter 2

Background

In this chapter, more background information is given about fNIRS. The functionality, advantages and disadvantages of fNIRS are described in detail. Also, the study of Carius et al./ [9] is included, which shows the robustness of fNIRS to motion. Furthermore, a brief overview of the gained insights from two pilot experiments that were conducted, is given.

2.1 fNIRS

Functional Near-Infrared Spectroscopy (fNIRS) is a non-invasive way to measure brain activity. Measurements that are obtained by fNIRS are based on the hemodynamic response. More specifically, the idea of fNIRS measurements is based on the fact that neuronal activity is fueled by glucose metabolism in the presence of oxygen [12]. This means that when a certain part of the brain is more active, more glucose is consumed. The blood flow is then adjusted towards these areas. This change in blood flow can be measured using fNIRS.

Within fNIRS measurements, a distinction can be made between oxygenated hemoglobin (O2Hb) and deoxygenated hemoglobin (HHb), where hemoglobin is a red protein responsible for carrying oxygen in the blood. O2Hb is the form of hemoglobin with the oxygen bound, whereas HHb does not have this bound to oxygen. O2Hb may also be referred to as oxy-Hb and HHb may also be referred to as deoxy-Hb or Hb. In this study, the abbreviations O2Hb and HHb will be used. During an activity, the rate of O2Hb delivery generally exceeds the rate of oxygen usage [12]. This results in a peak in O2Hb concentration which is often accompanied by a decrease in HHb concentration. As the delivery of oxygen is not instant but takes some time to reach the activated part of the brain, a delay of around 2 seconds can be expected between activation and oxygen delivery. This means that fNIRS measurements do not represent the current brain activity, rather the activity of 2 seconds ago.

As the name suggests, fNIRS uses near-infrared light to measure this change in blood flow. O2Hb and HHb are known to scatter near-infrared light in the range of 700-1000 nm, whereas most other biological tissues are transparent to near-infrared light [12]. By placing near-infrared light emitters and detectors on the scalp, changes in O2Hb and HHb concentrations can be detected.

One of the major advantages of using fNIRS is its robustness to movements (as already mentioned in Chapter 1). Whilst the more commonly used measurement method, EEG, has better temporal resolution, it is highly vulnerable to movement artifacts. As the execution of a penalty kick involves a lot of (irregular) movement, the use of EEG seems inappropriate. The robustness to movements of fNIRS has been demonstrated by Carius et al./ [9]. In their study, brain activity was measured during bouldering, which is a special form of climbing without a rope. In bouldering, complex whole-body movements are involved. The brain activity during simple climbing routes was compared with moderate climbing routes. The main focus was on the level of activation in the sensorimotor area. In total 13 participants were included. Results show that during the activity, almost all areas of the sensorimotor system were activated. No difference was found between simple and moderate climbing routes. Most importantly, this study shows that fNIRS is capable of measuring brain activity during the execution of heavy and irregular movements. As bouldering involves more extensive movements than kicking a ball, it should be possible to measure brain activity during the physical execution of penalty kicks as well, without the presence of significant artefacts.

Another advantage of fNIRS is its rather good spatial resolution. Where EEG is known for having a poor spatial resolution and an excellent temporal one, for fNIRS, the opposite applies. The spatial resolution of fNIRS goes up to 1 cm [13], which is significantly better than the 22-37 cm spatial resolution of EEG (using a 19-electrode system) [14]. However, the temporal resolution of fNIRS (around 10 Hz maximum) is considerably worse than EEG (up to a 1000 Hz maximum) [15]. As emotions, stress and worry have a rather long timestamp (around a few seconds at least), a temporal resolution of 10 Hz should be sufficient to measure these elements. The Brite equipment of Artinis even allows for a sample rate up to 50 Hz, which means the temporal resolution can be quintupled[2].

Besides its lower temporal resolution, there is another disadvantage of using fNIRS. Although it is in general difficult to measure brain activity deep within the brain, fNIRS is considered to be insufficient for measuring these areas. fNIRS is mainly of use for measuring activity at the outer surface of the cortex. With EEG it would still be possible to measure activity deep within the brain, however, fNIRS only has a depth sensitivity of 1.5 cm [13]. Therefore only activity close to the scalp can be measured. As most regions of interest for this research are located in the outer surface of the cortex (see Section 3.2), fNIRS can be used for this study.

In recent years real-time motion artifact removal for EEG has been extensively researched [16–19]. The results of these studies are promising, as the robustness of EEG measurements to motion artefacts is increased. This could vouch for the use of EEG instead of fNIRS, however, additional sensors are often needed in order to remove the artifacts in real-time and a long calibration is necessary. Furthermore, in all the above mentioned studies, no extensive movements were considered. In most of these studies, the participants were seated during the experiment, which means only minor movements were involved. Therefore fNIRS is still preferred over EEG for this study.

2.2 Pilot Tests

Before this study, two pilot tests were done. The first pilot test was done in order to get some first insights into the brain activation whilst being under pressure and to design and evaluate the method and data analysis pipeline. The second pilot test was done in order to evaluate the newly designed methods for pressure induction.

From the first experiment, it became clear that the used methods for pressure induction

[2]Information obtained from: *https://www.artinis.com/brite#brite-fnirs-system-section*

were not sufficient, as the participants indicated that they did not experience an increase in pressure when it was intended. The methods used to induced pressure were: the winner got a prize (Ben & Jerry's ice cream), the players were allowed to distract one another and the players were allowed to use trash-talk on each other. During this pilot experiment,the participants were playing a game of darts. It also became clear that the used pre-processing steps for the fNIRS data were too strict. Channel data was namely kept or removed based on the standard deviation of that channel. Using this method a large part of the data was removed, leaving a small amount of data for the analysis. Still some interesting findings were done. The connectivity between the dorsolateral prefrontal cortex (DLPFC) and the motor cortex was namely clearly larger whenever the participants were hitting their darts (performing) during the highest pressure condition. This assumes that this connectivity would be related to performing under pressure.

During the second pilot experiment, different methods to induce pressure were tested to see if these were more successful. During this experiment, experienced football players were taking penalties and the State-Trait Anxiety Inventory (STAI) questionnaire [20] was used to measure the level of pressure. In order to induce pressure, the football players were distracted by the goalkeeper; the goalkeeper constantly called the player by their first name and the player had to indicate beforehand to the goalkeeper in what corner they were going to shoot the ball. From this pilot experiment, it became clear that these methods to induce pressure were not successful and that the STAI questionnaire was not sufficient to measure stress/anxiety during sports. A questionnaire that is more specifically related to performance-anxiety would be more sufficient to use.

Both pilot tests are described in more detail in Appendix A.

Chapter 3

Related Work

In this chapter, a literature review is presented and discussed. This section contains the main insights that were gained in this literature review. The aim of this review to gain more information related to choking under pressure and penalty kicks. At first, existing theories about why penalties are missed are compared and discussed. Second, the fear circuit model of Hatfield and Kerick [21] is explained and discussed. All individual components of this model are further elaborated in the subsections. Third, other psychological factors, besides brain activity, that are related to stress and pressure are discussed. Fourth, the study of Kuriyama et al. [8] is discussed in detail, as this is the only study that has been found where brain activity is measured within a penalty kick situation. Fifth, commonly used data analysis procedures in fNIRS studies are discussed. At last, some conclusive remarks are given and a number of hypotheses are set-up.

3.1 Why Are Penalties Missed?

Over the years numerous studies investigated why penalties are missed, the most evident reason being the level of skill of the penalty kicker and goalkeeper. The placement and power of the shot [22–24] and the position and diving direction of the goalkeeper [25–31] have a significant influence on the outcome of the penalty. However, also other less obvious factors have an influence on the quality of the penalty and therefore on the outcome of the penalty. For example, the color of the jersey of the goalkeeper and kicker [32–36], playing at home [37], the status of the kicker or team [38, 39], the amount of time taken before shooting [6, 39–43], the run-up angle [44–46], being right or left-footed [37, 44, 47, 48] and the posture of the goalkeeper [49–51], all have an influence on the quality of the penalty kick (for more detail see the overview of Memmert et al. [52]). The majority of these examples are related to psychology (e.g. status of player or the pressure of playing in front of your own crowd). Meaning that besides technical skill, psychological factors seem to have a clear influence on the outcome of a penalty kick as well. In an analysis of all 41 penalty shootouts taken in the World Cup, European Championships and Copa America between 1976 and 2004, it was even found that only psychological factors had a large negative influence on the outcome of the penalty, where skill and fatigue did not [4].

The most common psychological factors that have been studied, regarding penalty kicks are the kicker's anxiety and the pressure that the kicker is under. A more anxious shooter is more likely to crack under pressure and therefore miss the penalty kick. This decrease in performance under pressure is also referred to as 'choking'. Chiappori, Levitt and Groseclose [28] found that the probability of scoring a penalty is lower in the last half hour of a game as compared to the first 15 minutes, suggesting that higher pressure (i.e. at the end of the match) negatively influences the outcome of a penalty. More recently, Arrondel, Duhautois and Laslier [5] analysed 252 penalty shoot-outs (sequence of penalties at the end of a match to decide a winner) in all the three French Cup competitions from 1995 until 2017 to see the effects of the stakes and risks of winning and losing on the scoring probabilities. They have found that when the stakes are high and there is a greater risk of losing, the probability of scoring a penalty is reduced. This even is the case for experienced kickers. Their results show that when there is is more at stake and there is a high risk of losing (i.e. high pressure), kickers are more likely to choke under pressure. In this study, the role of the goalkeeper was not taking into account. Similarly, Wilson, Wood and Vine [6] found that more anxious kickers shooting significantly more centralised and within the goalkeeper's reach. Also in many other sports this 'choking' effect has been found, such as weightlifting [53], golf [54], chess [55], basketball [56] and tennis [57]. This provides a solid basis that, besides technical skill, psychological aspects play a significant role in the performance of athletes, as it can cause them to choke under pressure.

3.1.1 The Theories Behind Choking

There are two dominant explanations of the existence of choking under pressure, focusing on either self-focus or distraction. Both theories have often been studied. Where the self-focus theory is often favoured in dual-task experiments, qualitative research supports the distraction theory. Below both theories are further elaborated.

The self-focus theory proposes that anxiety or pressure increases the level of self-consciousness, resulting in more consciously monitoring or controlling skill execution, and choke as a result [58–60]. This means that too much pressure leads to the undermining of automatism and therefore there is too much attention towards the execution of the skill. On the other hand, the distraction-theory proposes that anxiety or pressure occupies the working memory, causing a shift from task-relevant cues to task-irrelevant cues [58, 60–62]. This means that unlike the self-focus theory, too little attention is towards the execution of the skill. These distractions can be either internal (e.g. worries) or external (e.g. distracting fans).

The studies related to penalty kicks suggests that the distraction theory is more plausible. In laboratory experiments, it has been shown that more attention towards the goalkeeper results in less accurate penalties, as they are more directed towards the goalkeeper [6, 43]. Also distracting moves by the goalkeeper, have a negative influence on the quality of the penalty. It is therefore recommended for a goalkeeper to draw attention upon him- or herself, as this increases the chances of saving the penalty [49, 51, 52, 63]. The influence of attention towards the goalkeepers on the quality if the penalty kick, has also been analysed outside a laboratory experiment. An analysis of all penalty shoot-outs from 1984 to 2012 during FIFA World Cups and European Football Championships supports these laboratory experiments, as it was found that more attention towards the goalkeepers and when the goalkeepers distracted the kicker, resulted in more saves/better goalkeeping performance [64]. The circles of attention by Eberspächer [65] provide an overview of the different levels of distraction (see Figure 3.1.1). It can be seen that in order to have the optimal performance the player should be focused on him- or herself and the task. In this case, the task would be scoring a penalty. This is the centre of the circle. Every form of distraction will result in a decrease in performance. This is illustrated by the outer circles. When players are distracted their attention shifts from the centre circle to one of the outer circles.

From inner to outer circle the rings represent: **1.** focus on the task, **2.** focus on the directly surrounding environment (e.g. audience, opponents, referee etc.), **3.** focus on the comparison between the ideal world and reality (e.g. "What if I had trained more often on penalties?"), **4.** focus on the result (winning or losing), **5.** focus on the consequences (e.g. "If I miss this penalty my fans will be disappointed in me") and **6.** focus on the meaning of life (e.g. "What am I doing here? Why am I even taking this penalty? It is a waste of time"). According to this theory, pressure causes one's focus to shift from the middle of the circle to further outwards. Therefore the circles provide a nice overview on how pressure is related to the ability to focus on a task.

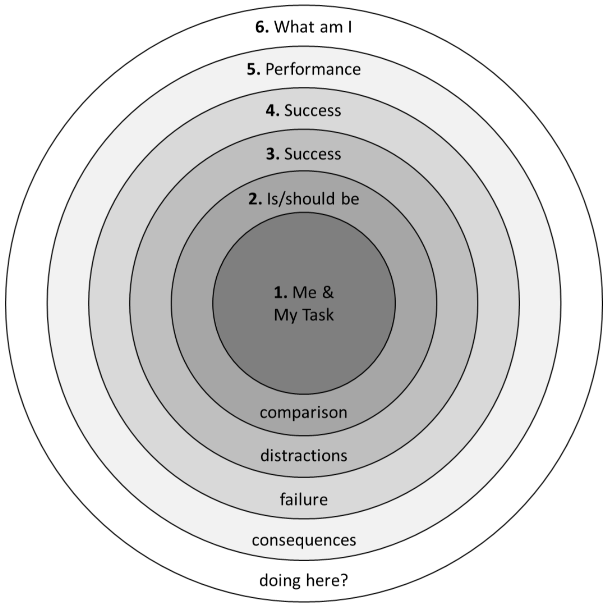

Figure 3.1: The circles of attention by Eberspächer [65]

On the other hand, studies have shown that adopting an external focus (e.g. focus on a target in the goal) improves motor performance as compared to an internal focus (e.g. focus on your leg whilst kicking the ball) [66–68]. This could be an argument for the self-focus theory, as it proves that an internal focus, being more conscious about your own movements, decreases performance. However, during these experiments participants were instructed to adopt an internal or external focus, meaning that there is no sign that the difference in focus is caused by pressure. Furthermore, as the negative impact of a distracting goalkeeper does not fit within the self-focus theory, the distraction theory seems more likely.

3.1.2 Neural Efficiency

The self-focus theory and distraction theory seem to be very different. However, when looking at the brain, it is arguable that the two theories are actually more similar than originally thought.

The "neural efficiency" hypothesis, namely posits that expert athletes show more efficient brain activity than non-athletes, meaning that task-relevant activities are increased and task-irrelevant activities are decreased. When executing a penalty kick (or any other sport related activity) the motor cortex is a task-relevant area, as the main goal is to perform a certain movement. Task-irrelevant areas as the prefrontal cortex (which is related to planning and long-term thinking, for example), should therefore be activated less. The optimal performance is therefore achieved by mostly activating task-relevant areas. This hypothesis is supported by literature, as it has been found that expert athletes have a higher activation in task-relevant areas [69–71] and a lower activation in task-irrelevant areas [11, 72–77]. The distraction theory and "neural efficiency" hypothesis are in agreement. Task-irrelevant activity can namely be seen as a distraction from task-relevant activities.

Consciously monitoring or controlling skill execution (and therefore neglecting automated skills) also activates task-irrelevant parts of the brain. Within the sports domain the left temporal cortex is considered to play an important role in conscious motor processing [78, 79]. A lower left temporal activity is also associated with higher expertise [11, 72–74, 80–83]. It has even been shown that under pressure left temporal activity is increased [79]. A higher level of conscious motor processing therefore increases task-irrelevant areas of the brain. Conscious motor processing causes irrelevant activity and a decrease of relevant activity. Wolf et al. [11] also argue that "under pressure athletes might redirect their attention to the execution of well-known automatic skills in order to consciously regulate their movement". Whilst being distracted your attention is also redirected towards task-irrelevant areas. It can therefore be argued that an increased level of self-consciousness is a form of (voluntary) distraction.

The self-focus theory and distraction theory are therefore not that far apart. Both namely focus on a certain kind of distraction. Arguably the self-focus theory can even be seen as a form of internal distraction.

3.2 Fear Circuit Model

All the above mentioned hypotheses and theories come together in the fear circuit model of Hatfield and Kerick [21]. This model, shown in Figure 3.2, provides an overview of the neurological processes underlying choking. Although this model is from 2007, results from more recent studies are still in agreement with the model. Therefore this model still seems relevant to use in this study.

In this section, the model is described in further detail. All individual components of the model are discussed in the subsections below. In these subsections the recent studies mentioned before are also included.

According to the model of Hatfield and Kerick [21] football players that experience high stress during a penalty kick, will have a lack of control over the prefrontal cortex. This will result in a higher activation in the limbic system and consequently also a higher activation in the left temporal region. This results in nonessential communication between the left temporal regions and the premotor cortex. The motor loop, consisting of the basal ganglia, thalamus, premotor cortex and the motor cortex, is therefore disturbed. Also, the inconsistent prefrontal activity will disturb the motor loop, as the prefrontal cortex and the basal ganglia are directly communicating. This disturbance in the motor loop (inconsistent input), results in inconsistent output and therefore the quality of the

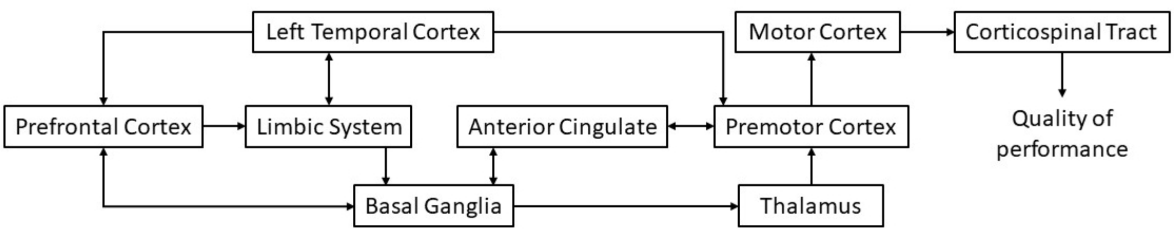

Figure 3.2: Neurobiological Model of the Fear Circuit, based on the work of Hatfield and Kerick [21]

performance also becomes inconsistent.

In the subsections below each individual area of the brain involved in this model is explained in detail. Other studies to choking related to these brain areas are included as well. The information given in the subsections below show that both the self-focus and the distraction theory fit within the Fear Circuit model. Namely, distraction is mostly related to activation in the prefrontal cortex and self-consciousness about your movements is related to activation in the left temporal cortex. Inconsistency in both of these regions will possibly lead to choking. Furthermore, efficient activation of the essential regions of the brain will result in higher quality performance. When task-irrelevant areas are over-activated, the motor loop will be disturbed. This shows that also the "neural efficiency" hypothesis fits within this model.

3.2.1 Prefrontal Cortex

In general, the Prefrontal Cortex (PFC) is related to planning (setting goals), focusing attention and managing emotional reactions. The PFC is located in the front of the brain (see Figure 3.3).

According to Korb [7] the long term planning element of the PFC causes a distraction. Because of this long-term planning ability, the PFC is aware of the consequences of our actions and thus of the consequences of missing or scoring a penalty. Korb states that an overactivation of the PFC causes choking. Someone who is able to silence their PFC will perform better under pressure. The study of Nosrati et al. [84] supports this theory, as they found that the PFC was significantly activated whilst someone was distracted from performing a motor task. In this case, the motor task was driving, general true/false questions were used as a distraction and fNIRS measurement equipment was used to measure the brain oxygenation. The activation induced by distraction was identified by an increase in O2Hb. This was mostly accompanied by a decrease in HHb. This activation was significant in both right and left PFC. These findings were in line with an earlier fMRI study using the same driving task and distractions [85]. Whilst distracted the left and right PFC are significantly activated. These areas are not activated when no distraction is present. In this study, it is also clearly observable that the medial prefrontal cortex (mPFC) is not activated in both the distracted and the not-distracted condition.

Also, Ito et al. [10] showed that there is an association between pressure-induced performance decrements and PFC overactivation in an n-back working memory task. Pressure was applied by offering money-based awards and pretending to monitor the performance of the participants. An overactivation was associated with an increase in O2Hb in both the left and right PFC. Only in the highest load task level the error rate and PFC activation were found to increase with pressure.

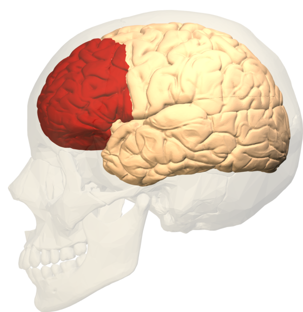

Figure 3.3: Prefrontal Cortex[3]

These studies show that PFC activity is task-irrelevant. Increased PFC activation namely causes decreased motor-skilled performance. This can be explained by the fact that increased PFC activation is associated with being stressed [86, 87]. Often footballer players themselves mention that stress or anxiety is a cause for

[3]Retrieved from: commons.wikimedia.org

missing penalties. When looking at studies outside of the sports domain, that measure PFC activation related to stress, contradicting results are found. On one hand, it has been shown that stress is related to a significant increase in O2Hb in the bilateral PFC [88, 89]. This indicates an increase in PFC activity when stressed. On the other hand, Al-shargie, Tang and Kiguchi [90] found a decrease in PFC activation when being stressed. Both studies were focused on mental arithmetic tasks. Therefore there seems to be some uncertainty regarding the activation of the PFC during stress.

A theory by Hatfield and Kerick [21] may explain these contradicting results. They namely state that not the overall (de-)activation of the PFC, but the reductions in prefrontal asymmetry indirectly causes choking. Prefrontal asymmetry refers to the difference between left and right PFC. This would explain why both an overall increase and an overall decrease of PFC activation were observed in the studies mentioned above. The asymmetry between left and right PFC is namely more important than overall PFC activation. Stress can namely be observed when both left and right PFC have increased activation (meaning an increase in overall PFC activation) and when both left and right have decreased activation (meaning a decrease in overall PFC activation). Furthermore, it has been shown that higher activation in the right PFC, as compared to the left PFC, is associated with reduced motivation and higher stress and anxiety, while a higher left PFC activation, as compared to right PFC, is associated with increased motivation and resilient behaviour [91]. This suggests that a higher left PFC activation corresponds to better performance in exercise/sports [92]. Therefore choking will be most possibly characterised by an increase in right PFC activation and a decrease in left PFC activation.

3.2.2 Basal Ganglia

In general, the basal ganglia is associated with the planning of movements, memory, emotions and attention. The basal ganglia is located in the centre of the brain (see Figure 3.4).

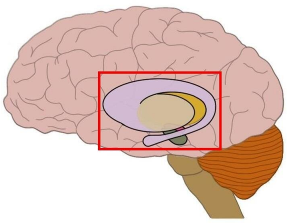

Figure 3.4: Basal Ganglia[4]

Not a lot of studies has been done regarding the involvement of the basal ganglia in choking under pressure. For a long time it was believed that the brain's emotion and movement loops worked independently, although there were also suspicions that the emotion loop has an influence on the movement loop [93]. Recently it has been discovered that the basal ganglia functions as a one-way communication pathway from the emotion loop to the movement loop [93]. This allows the emotions loop to influence the movement loop, but not vice versa. These results again show that emotions directly influence the execution of movements and therefore also directly influence performance in sports. This means that potentially a higher activation in the basal ganglia could be related to choking, however, no study has been found that looked into this. As the basal ganglia is located quite deep in the brain it is difficult to measure, especially using fNIRS. This could explain the absence of studies into the basal ganglia and its relationship with choking.

[4]Retrieved from: https://www.neuroscientificallychallenged.com/blog/what-are-basal-ganglia

3.2.3 Thalamus

The thalamus mainly acts as a relay centre from the spinal cord and brainstem to the cerebral cortex. The thalamus is located in the centre of the brain (see Figure 3.5). The thalamus is known to be involved in motor control, as it is in between the cerebral motor areas and the motor-related subcortical structures (such as the basal ganglia) [94, 95]. Similar to the basal ganglia, the thalamus also seems to act like a pathway, with the cerebral cortex as destination. However, there is a more advance interplay between the thalamus and the cerebral cortex. The connectivity between the two is responsible for "the flow of images in one's stream of thought" [96], meaning that the thalamus helps in visualizing one's thoughts. The thalamus is therefore considered to play an important role regarding consciousness. Although self-consciousness is a common source of choking (see Section 3.1.2), no study has been found regarding the relationship between the thalamus and choking under pressure.

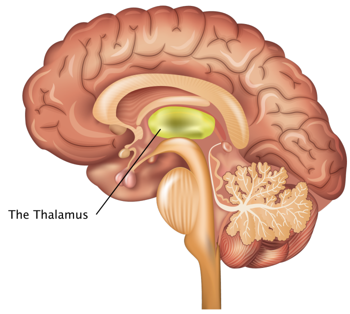

Figure 3.5: Thalamus[5]

3.2.4 Premotor Cortex

The premotor cortex is involved in movement control and therefore very important in physical sports like football. More specifically, its function is to prepare the muscles for the exact movements that will be made. The premotor cortex is located in between the PFC and the motor cortex (see Figure 3.6). In studies related to the premotor cortex and choking, some interesting results were found. Namely, there is a link between premotor cortex activity and rewards. Mobbs et al. [97] namely suggest, based on their results, that the premotor cortex (more specifically the bilateral ventral premotor area) is involved comparing the value of a reward and the amount of effort it would take to gain the reward. It is involved in determining how much motivation one has for a certain reward. Premotor cortex activity was significantly higher for a combination of higher rewards and easier tasks. Similarly, Lee and Grafton [98] state that premotor activity is significantly increased for increasing rewards. As motivation is closely linked to the rewards, the premotor area could be an interesting area to investigate. It is namely arguable that a higher premotor activation is related to higher motivation and without motivation, people will not choke. An increased activation of the premotor cortex could therefore be related to choking under pressure.

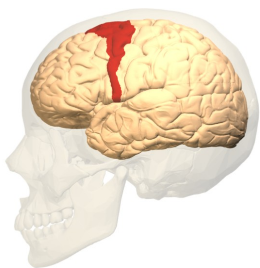

Figure 3.6: Premotor cortex[6]

Furthermore, synchronized activity between the premotor area and the dorsolateral prefrontal cortex (DLPFC), which is a small area in the PFC, has shown to reduce the chances of choking. This is according to the study of Lee and Grafton [98] and more explanation on this can be found in the next section (Motor Cortex - Section 2.3.5).

[5]Retrieved from: https://www.thescienceofpsychotherapy.com/glossary/thalamus/
[6]Retrieved from: https://www.psychologytoday.com

3.2.5 Motor Cortex

The motor cortex controls the execution of movement. The motor cortex is located right next to the premotor cortex (see Figure 3.7). As the motor cortex is directly responsible for the execution of movements, the link between motor cortex activity and sports performance has been studied. Wolf et al. [69] showed that expert table tennis players show a higher motor cortex activation than novice players. This higher activation was reflected by clear 8-10 Hz event-related desynchronization (ERD). This low-level ERD is associated with more complex movements. This indicates that experts show increases motor cortex (task-relevant) activation, which is in line with the "neural efficiency" hypothesis. This would indicate that increased motor cortex activity would lead to better performance.

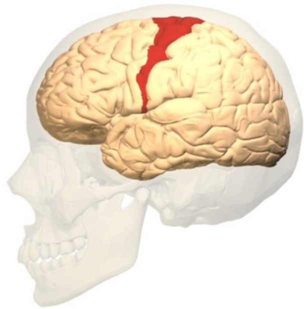

Figure 3.7: Motor cortex[7]

Where Wolf et al. just focused on the motor cortex, Lee and Grafton [98] looked into the functional connectivity between the PFC and the motor cortex. Where functional connectivity refers to a statistical relationship between the activity of two regions [99]. In their experiment participants had to play a challenging game based on the classic arcade video game *Snake*. After some training, the participants could earn a reward ($5, $10 or $40) if they could successfully complete a trail. The awards were picked pseudorandomly. They found that choking under pressure led to increased functional connectivity between the motor cortex and the PFC (more specifically the dorsolateral prefrontal cortex - DLPFC). This suggests that the involvement of the PFC in the motor cortex processes causes choking, which is in line with the theories and findings presented in Section 3.2.1 and in line with the "neural efficiency" hypothesis. However, when the researchers examined whether this change in connectivity affected the performance, they found contradicting results. Namely, participants who showed the greatest increase in connectivity from the $10 condition to the $40 condition, choked the least. This was measured by comparing the accuracies between $10 and $40 trials. The larger the increases in functional connectivity, the more likely participants were to show maintained performance. These results show that increasing connectivity protects against choking rather than causing choking. This contradicts with the idea that the PFC is a distracting activity. In fact, Lee and Grafton state that increased prefrontal involvement could signal a resistance against distraction. It has to be noted that the study of Lee and Grafton did not look into the connectivity between the motor cortex and the overall PFC. Only the connectivity with the DLPFC was considered and this area of the PFC is related to cognitive control. Other studies also found that during performance failure due to distraction, functional connectivity between DLPFC and important motor performance related areas decreased [100, 101]. Lee and Grafton [98] found similar findings for the connection between the premotor cortex and the DLPFC.

These studies show that an increase in motor cortex activity could be beneficial for performance, as experts show increased motor cortex activity as compared to novices. Furthermore, the connectivity between the DLPFC and the motor cortex seems to be important for dealing with pressure. A higher connectivity between these regions reduces the chances of choking.

[7] Retrieved from: http://www.brainmatters.nl/terms/primaire-motorcortex/

3.2.6 Limbic System

The limbic system is involved in behavioural and emotional responses, especially regarding survival. Feeding, caring, fight or flight responses and reproduction are examples of the functionalities of the limbic system. It is located deep within the brain, just above the brainstem (see Figure 3.8). Important parts of the limbic system are the thalamus, amygdala and hippocampus. No study has been found where the relationship between limbic activity and choking was examined. However, it has been shown that deactivation of the limbic system corresponds with higher stress levels [102]. It has to be mentioned that this study focused on acute psychosocial stress, which seems to be unlikely to occur during a penalty kick. Psychosocial stress is namely related to unrealistic demands. Executing a penalty kick does not seem like an unrealistic demand.

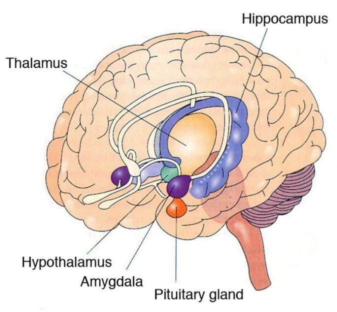

Figure 3.8: Limbic System[8]

More studies have been done regarding the relationship between stress and the limbic system. It has for example been shown that stress induced by negative social feedback, when a reward was anticipated, results in increased amygdalar activation [103]. Furthermore, responsiveness and interconnectivity are increased in the amygdala when exposed to an acute stressor [103, 104].

Although the link between stress and the limbic system is well established, no study has been found looking into the involvement of the limbic system in choking under pressure.

3.2.7 Anterior Cingulate

The anterior cingulate cortex (ACC) is associated with empathy, impulse control and emotion. The ACC is located towards the front of the brain and left of the basal ganglia (see Figure 3.9). In studies related to choking it has been shown that the ACC is related to emotion control. Namely, deactivation of the ACC is related to people who react to a stressor [102]. On the other hand, increased activity in the right ACC is correlated with a better performance [97]. This gives an indication that the ACC is involved in emotion control. Namely, by activating the ACC stress levels are reduced, whereas a lack of ACC activity corresponds to increased stress levels. However, it has to be mentioned that the ACC is also engaged in saliency detection and therefore it may not per se encode stress in the previous named studies [103]. Overall, there is still some uncertainty about the involvement of the ACC in choking. Although there seems to be a relationship between stress and ACC deactivation, this relationship could be coincidental.

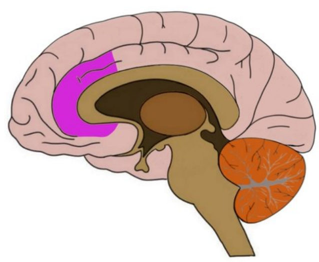

Figure 3.9: Anterior Cingulate Cortex[9]

[8]Retrieved from: https://nl.pinterest.com/pin/531284087283367460/
[9]Retrieved from: https://www.neuroscientificallychallenged.com/

3.2.8 Left Temporal Cortex

The temporal lobe's main functionality is related to language and speech. The temporal lobe is located on the side of the brain, behind the ears (see Figure 3.10). A lot of studies have been done regarding the influence of the temporal lobe (mainly left temporal cortex) on sports performance. Already in the 1980s, Hatfield et al. [80–82] showed that only expert shooters have lowered left temporal activity in the preparatory period before shooting, whereas for novice shooters this activity remained constant. Using EEG an increase in alpha power (8-12 Hz) in the left temporal region (T3) was measured for expert shooters. Novice shooters did not show this increase. An increase in alpha power is associated with less cognitive demands, meaning that less activity is observable [105]. Contrary, the right temporal region (T4) remained constant. In more recent studies the same results were observed [72, 73, 83], even in other aiming sports like archery [106] and biathlon shooting [107]. It is clear that in shooting and other aiming related sports, there is a difference in brain activity observable at the left temporal region between experts and novices.

Figure 3.10: Left Temporal Cortex[10]

The same difference can be observed in other sports. Also, table-tennis experts show higher alpha activity in the left-temporal region compared to novices, whilst the right temporal region remained constant [11]. Furthermore, a higher left-temporal alpha activity corresponded to more world rank points (i.e. a higher level of skill). This shows that even between different experts a distinction can be made when looking at left-temporal alpha power activity. Wolf et al. [11] associate this reduced left temporal activity with more 'flow-experience'. On the other hand, increased left temporal activity is associated with self-instruction and disturbing thoughts. It is therefore believed that novices are more self-conscious about their motor processes, whereas experts, because of their higher level of expertise, have automated the skill and therefore do not have to think that much about it. Wolf et al. also argue that because of mental pressure, experts will neglect their automated skills and start to consciously monitor their own motor processes. This would mean that under pressure left temporal activity would increase. The study of Zhu et al. [79] supports this hypothesis of Wolf et al., as they have found an increase in left temporal activity under pressure in a golf putting task.

Furthermore, Wolf et al. [11] also argue that novice players do need to activate their left temporal cortex in order to perform. Where experts should minimize their left temporal cortex activation, novices should activate it more. They namely found that novice table tennis players are having a flow-experience when their left temporal cortex is more activated. This could be explained by the fact that self-instruction and self-monitoring are crucial in the early stages of motor skill learning. As novice players have not automated the motor skills needed for playing table tennis, it is better to instruct and monitor themselves more in order to learn.

This shows that the left temporal cortex is directly related to choking. Experts show a decrease in activity in this region, whereas the right temporal cortex remains constant. An increase of left temporal activity is an indication of choking for experts. Whereas, novices should activate their left temporal cortex more in order to perform.

[10]Retrieved from: http://www.neurocogmed.com/article1.htm

3.2.9 Corticospinal Tract

The corticospinal tract (CPT) is the main spinal pathway involved in voluntary movements. It is connected to the motor cortex (see Figure 3.11). The CPT is necessary for transferring information from the motor cortex to the muscles. Although this tract is directly involved in the execution of movements, no link between CST activity and choking has been found. Also, no relationship between stress or anxiety and the CSP was found. The CSP seems to simply communicate information from the motor cortex, no alternations are made.

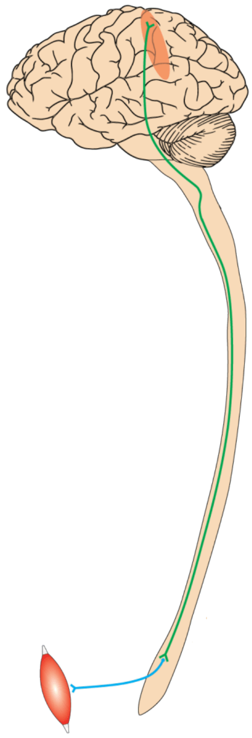

Figure 3.11: Corticospinal Tract[11]

3.3 Other Psychological Factors

Besides brain activity, other psychological measurements can be used to detect stress or choking. It is well known that stress will lead to increased blood pressure, increased muscle tension and your heart rate to speed up [108]. It has also been shown that autonomic arousal (a combination of heart rate, skin conduction, skin temperature and blood volume pulse) increases [10].

A lot of studies related to penalty kicks looked into the eye gazing directions of the kicker, to see if he or she was distracted. As explained in Section 3.1, the distracting role of the goalkeeper has been extensively studied over the years. It was namely found that the (off-centre) position, posture and distracting moves (e.g. waving with arms) increase the chances of saving the penalty kick [25, 43, 49–51]. The aim of the goalkeepers should namely always be to draw attention upon him- or herself. By making use of eye-tracking equipment, the distracting impact of the goalkeeper can be measured. It has been shown that a longer fixation on the goalkeeper, corresponds to lower quality penalties [6, 43, 64]. This shows that the goalkeeper is a distracting factor, which has an impact on the quality of the penalty kick.

Besides the goalkeeper, there are other potential distracting elements during a penalty kick. An obvious distracting factor could be the crowd. Especially when playing an away match the opposing crowd will try to distract the kicker by waving or making noises. Surprisingly, the distracting factor of the crowd has not been extensively studied. Although it has been established that the presence of a crowd increases pressure and the presence of an audience is often used to induce high levels of stress [109, 110], the direct effect of distracting moves by the crowd has not been looked into. Also the possibly distracting role of a referee has not been studied. It has, however, been shown that moving advertisements behind the goal negatively impact the accuracy of penalty kicks [111]. A moving advertisement caught the visual attention of the kickers and therefore was a distracting factor. As a result, the penalty kicks were more variable (i.e. less consistent) as compared to no or a stationary advertisement. Although the moving advertisement

[11] Retrieved from: https://brainmadesimple.com/corticospinal-tract/

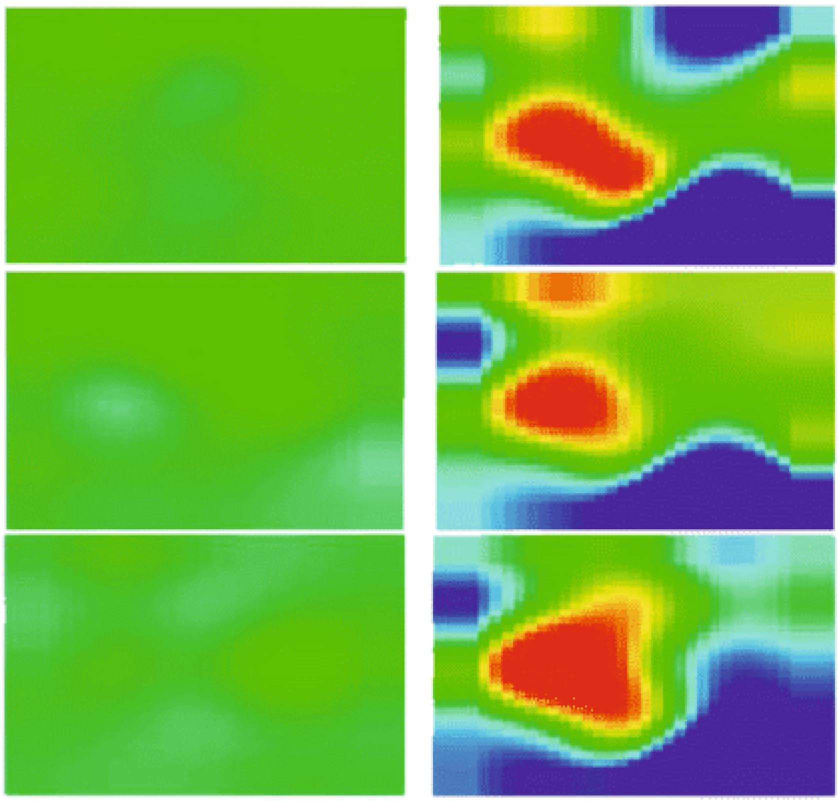

Figure 3.12: The averaged results of novices (left) and experts (right) measured over the prefrontal cortex - blue indicates low activity and red indicates high activity. No further information is given by Kuriyama et al., so the meaning of the x and y-axis is unclear [8]

caught more attention and this seemed to have a negative impact on the shot-accuracy, no significant difference in penalty outcome (i.e score or miss) was found. Meaning that although penalties were aimed less well, it had no significant impact on the outcome in this study.

As mentioned before, Nosrati et al. [84] and Schweizer et al. [85] found a significant increase in PFC activation when being distracted from a motor task. For both studies the motor task was driving-related. While Schweizer et al. used fMRI to measure the brain activity, Nosrati et al. used fNIRS. This shows that distraction can be measured using fNIRS and that PFC activation is related to this.

In short, the above mentioned studies show that autonomic arousal and its individual elements can be used to measure stress and eye-tracking can be used to establish how much the kicker is distracted. These psychological measurements can be used to confirm if a kicker is stressed or distracted. It is therefore useful to, besides brain activity measurements, also measure autonomic arousal and eye gazing. This way the measurements can be compared to see if they are in agreement.

3.4 Penalty Kick Studies

Only one study has been found that measured brain activity during a penalty kick. This study was conducted by Kuriyama et al. [8] and in this study, fNIRS was used to measure the brain activity of a goalkeeper during a penalty kick. The study (N=8) is focused on different levels of expertise, so both experts and novice goalkeepers participated. Participants were seated and had to watch a clip of a kicker placing down the ball, running up towards the ball and kicking the ball. No actual physical goalkeeping actions were involved. Prefrontal activity was measured. The results show that expert goal-keepers have stronger prefrontal activity and the highest activity was observed when the ball was kicked. Regarding novices, lower prefrontal activity was observed and when the ball was kicked, no difference in activity was observed. The results are shown in Figure 3.12.

Kuriyama et al. [8] concluded that experts show higher prefrontal activity, however, when looking at the results in Figure 3.12 there is not just increased activity all over the PFC. Even some areas show decreased activation. Therefore their conclusion does not seem fitting. A more suiting conclusion would be that for experts there is a higher contrast in prefrontal activity as compared to novices. Furthermore, when looking at the PFC activity for expert goalkeepers, it seems that the left PFC is more activated than the right PFC. This would be in line with the results presented in Section 3.2.1, as it was concluded that increased left PFC activation would correspond with better performance. However, Kuriyama et al. are unclear about the orientation of their plots. No information is given if both left and right PFC are measured and if the left side of the plot also corresponds to the left PFC. Therefore, no conclusions can be made about increased left PFC activation.

As only one study could be found related to penalty kicks, it shows that no extensive research has been done in this field. The brain activity of the kicker has not yet been measured and no measurement has been done during the actual activity. Furthermore, no pressure was applied on the participants.

3.5 Data Analysis

From the studies discussed in the above sections, it can be determined that the PFC, the left temporal cortex and the (pre)motor cortex play vital roles in choking. More specifically, an overall higher PFC activation, higher symmetry between left and right PFC activation, higher left temporal activation, lower motor cortex activation and lower connectivity between (pre)motor cortex and DLPFC have all been related to choking. There are other areas of the brain involved in the fear circuit model, however, these areas either have a less significant impact or are more difficult to measure using fNIRS because of their deeper location within the brain.

Now that the brain regions of interest are known it is important to establish methods for analysing fNIRS data. At first the recorded data needs to be pre-processed. Although fNIRS is more robust to movements, there will still be artefacts in the data, both motion-related and psychological-related. In order to reduce this noise, the data will be bandpass-filtered and detrended, as these are commonly used practices [112]. Furthermore, noisy channels need to be removed. This can be done manually or based on the within-subject standard deviation [113]. If the standard deviation of a channel is above a certain threshold, it is considered to be too noisy and therefore needs to be removed. Other, more advanced, methods to remove/reduce motion artefacts are Independent Component Analysis (ICA) [114] and Temporal Derivative Distribution Repair (TDDR) [115]. In the ICA method, the fNIRS signal is separated into a number of components and the components with high correlation with motion artefacts are removed. The TDDR method removes motion artefacts by looking at the changes of the fNIRS signal. If these changes are too rapid or steep, the signal is altered. Major advantage of this method, is that there is no need to make assumptions about the distribution of the data (e.g. need to assume a normal distribution).

As explained in Section 2.1, when using fNIRS, there are two types of data per channel: O2Hb and HHb. Similar to EEG measurements, it is necessary to compare the fNIRS data during activity or stimuli to a period of rest. Ito et al. [10] included a period of rest in between each load level of an n-back working memory task (1-back, 2-back and 3-back). This rest period is then used as a baseline. The average baseline activity is subtracted from the brain activity during the actual activity/stimuli.

It is very common in fNIRS studies to compare the average brain activity of different groups with each other. For these comparisons, the ANOVA statistical test is often used [10, 98]. This test allows to determine whether the data of two different groups are significantly different. Ito et al. [10] used this ANOVA test to see whether there is a significant difference in PFC activation between people that are put under pressure and people that are not put under pressure. Besides ANOVA tests, also permutation tests are often used [116]. These tests require more processing power and are therefore becoming increasingly popular in recent years, as the processing power of computers has increased. Permutation tests have the advantage that no statistical power is lost due to an excessively strict correction for multiple comparisons [116].

In order to determine the connectivity between areas of the brain, it is common to use Pearson correlation coefficients [117]. This coefficient tells something about the similarities between two fNIRS channels. If the channels show similar activity, it means that the connectivity is high.

3.6 Overview

In this section, a literature review was given, which aimed to find more information on choking and in particular the relationship between choking and brain activity during a penalty kick. Based on the model of the fear circuit by Hatfield and Kerick [21], the brain areas involved in choking during sports were established. These areas were the prefrontal cortex, basal ganglia, thalamus, premotor cortex, motor cortex, limbic system, anterior cingulate, left temporal cortex and the corticospinal tract. Due to the deeper location of the basal ganglia, thalamus, limbic system, anterior cingulate and corticospinal tract, these areas cannot be measured using fNIRS. This means that the brain regions of interest (ROI) for this study are the prefrontal cortex, premotor cortex, motor cortex and left temporal cortex.

In Table 3.1, an overview is given of all the findings in the literature corresponding to the ROIs. Based on the findings presented in this table, a number of hypotheses can be made.

At first, an increased prefrontal cortex (PFC) activation will lead to choking. This hypothesis is based on the theories of Korb [7], who states that the overactivation in the PFC will act as a distraction in the brain. This theory is supported by studies that found that an increase in PFC activation is associated with being distracted from a physical task and with being stressed. However, the studies of Al-shargie,Tang and Kiguchi [90] and Kuriyama et al. [8] are not in line with this theory. First, Al-shargie,Tang and Kiguchi found a decrease in PFC activation when being stressed, which is the exact opposite of the findings of other studies. Second, Kuriyama et al. found an increase in PFC activity for expert goalkeepers. When overactivation in the PFC is associated with choking, it would be expected that experts would show decreased PFC activation, as they are more experienced and familiar with the situation than novices. Although there is some inconsistency about this theory, it will still be interesting to test this theory during this study and see whether the assumptions of Korb are true. Therefore this hypothesis is included within this study.

Second, reductions in PFC asymmetry will lead to choking. This theory by Hatfield and Kerick [21] is also related to the PFC. However, instead of the overall activation, this theory is focused on the asymmetry between left and right PFC activation. When the asymmetry between left and right PFC is reduced (meaning that left and right PFC show similar activation), choking is more likely happen. This theory is supported by other studies, that suggest that an increase in performance is associated with higher left compared to right PFC activation. This theory could explain the inconsistency between different studies within the first hypothesis, as within the first hypothesis the differences between left and right PFC were not considered.

Third, an increase in motor cortex activity is associated with being less likely to choke. This hypothesis is based on the neural efficiency theorem and the results of the study of Wolf et al. [69]. According to the neural efficiency theory, optimal performance is achieved when only task-relevant areas of the brain are activated. When performing a sport related exercise, like a penalty kick, the motor cortex can definitely be seen as a task-relevant area. It is therefore expected that in order to perform well the motor cortex should be activated more. This is supported by the findings of Wolf et al. [69], as they found an increase in motor cortex activation for expert table tennis players. When choking the optimal performance is not achieved, therefore it is expected that when choking a decrease in motor cortex activation is observable.

Fourth, increased connectivity between dorsolateral prefrontal cortex (DLPFC) and the (pre)motor cortex will protect against choking. Lee and Grafton [98] found that during the condition in their experiment where the most pressure was induced, participants who had an increased connectivity between the DLPFC and the motor cortex were able to maintain their level of performance. In other studies, also the opposite has been observed, namely a decrease in connectivity between DLPFC and the motor cortex during performance failure. It is therefore expected that during choking, a decrease in DLPFC - motor cortex connectivity is observable.

At last, an increase in left temporal cortex activation is associated with choking for experts. This hypothesis is backed by many studies related to aiming sports. In these studies, it was found that experts show lowered left temporal activity, as compared to novices. This phenomenon has also been observed outside the aiming sport domain, namely in table tennis. Wolf et al. [11] argue that under pressure the left temporal cortex can be increasingly activated due to self-instruction and the neglecting of automated skills, which could lead to choking. For novices, Wolf et al. [11] argue that the opposite is the case. Novice players should increase their left temporal cortex activation in order to perform.

3.7 Hypotheses

Based on the findings in the related work, a number of hypotheses have been set-up that are possible answers for the research questions. The research questions can be found in Section 1.3. The hypotheses are based upon the information shown in Table 3.1, which contains an overview of the main findings in the literature review. These hypotheses are listed below:

- **H1**: The prefrontal cortex (PFC) is more activated whilst being anxious during a penalty kick.
- **H2**: The PFC is more activated when missing a penalty - failing to perform.
- **H3**: The PFC activation is more symmetrical (stronger right PFC activation) when missing a penalty.
- **H4**: The PFC activation is more symmetrical (stronger right PFC activation) when being anxious during a penalty kick.
- **H5**: The motor cortex is less activated when being anxious during a penalty kick.
- **H6**: The motor cortex is more activated when scoring a penalty.
- **H7**: Experienced football players show a higher motor cortex activation than inexperienced players during a penalty kick.
- **H8**: A stronger average connectivity between the DLPFC and the motor cortex (z-values) is related to scoring a penalty whilst being anxious - performing under pressure.
- **H9**: More connected channels between the DLPFC and the motor cortex (number of connections) is related to scoring a penalty whilst being anxious - performing under pressure.
- **H10**: Inexperienced players show a stronger left temporal cortex activation than experienced players during a penalty kick.
- **H11**: Experienced players show a higher left temporal cortex activation when being anxious as compared to not being anxious during a penalty kick.
- **H12**: Inexperienced players show a lower left temporal cortex activation when being anxious as compared to not being anxious during a penalty kick.
- **H13**: Experienced players show a higher left temporal cortex activation when missing a penalty.
- **H14**: Inexperienced players show a lower left temporal cortex activation when missing a penalty.

An "in the wild" experiment was set-up in order to test these hypotheses. In this experiment, both experienced and inexperienced football players took several penalties whilst their brain activity was measured. Within this experiment different ways to induce pressure were implemented. This experiment is described in Chapter 4 and the results of this experiment are described in Chapter 5.

Brain area	Signal characteristics	References
Prefrontal Cortex	- An overactivation in the PFC causes a distraction, which leads to choking.	[7, 84, 85]
	- An increase in PFC activation is associated with being stressed.	[86–89]
	- When stressed a decrease in PFC activation is observable.	[90]
	- Reductions in prefrontal asymmetry lead to choking.	[21]
	- Higher left compared to right PFC activity is suggested to correspond to a better performance	[91, 92]
	- Expert goalkeepers show increased PFC activity.	[8]
(Pre)motor cortex	- Premotor activity is significantly increased for increasing rewards.	[98]
	- Increased connectivity between DLPFC and (pre)motor cortex protects against choking.	[98]
	- During performance failure due to distraction, connectivity between DLPFC and the motor cortex decreases	[100, 101]
	- Expert table tennis players show higher motor cortex activation than novice players	[69]
Left Temporal Cortex	- Experts in aiming sports and table tennis show lowered left temporal activity, as compared to novices.	[11, 72, 73, 80–83, 106, 107]
	- Under pressure, left temporal activity increases for experts. This could potentially lead to choking	[11, 79]
	- Novice players would need to activate their left temporal cortex more in order to perform. Under pressure, a potential decrease in left temporal cortex activation might be observable	[11]

Table 3.1: Overview of the main findings in the literature review for the ROIs

Chapter 4

Method

In this chapter, the method is described. This includes details about the participants, the experiment itself, the equipment and the data analysis approach. Furthermore, there is additional information about the methods used to induce and measure pressure. Some pictures of the experiment can be found in Figure 4.1.

4.1 Participants

In total 22 participants (12 males and 10 females, age avg: 22.9 yrs, std: 2.00) participated in the study. Out of these participants, 10 were experienced football players and 12 were inexperienced. Inexperienced players had either never played football before or just a few times a very long time ago. Out of these inexperienced players, six played a different competitive sport. All experienced players were part of either the first male or female team of vv Drienerlo (the football association of the University of Twente) and therefore trained and played matches regularly. The majority of participants were Dutch, however also participants of other cultures joined. This varied from other European cultures to Asian cultures.

All participants were right-footed, with an average Laterality Quotient of 77.27. This indicates that the use of the right hand/foot is preferred. The short form of the Edinburgh Handedness Inventory by Veale was used to calculate this quotient [118]. One question was added to this inventory in order to also determine the preferred foot for kicking.

The Sport Competition Anxiety Test (SCAT) was used to get an indication of the level of performance anxiety of the participants [119–121]. In total, eight participants could be categorised as having low performance anxiety, eleven as having average performance-anxiety and three as having high performance-anxiety. The possible SCAT scores range from 10 to 30 and the average anxiety score of all participants was 18.3.

4.2 Task

During the experiment, the participants had to take 15 penalties in total, equally divided over 3 rounds. For every penalty, the same rules apply. The player has to place the ball on the penalty spot, which is 11 meters away from the centre of the goal. Before the penalty can be taken, the player must wait for the referee to blow the whistle. The goalkeeper has to stay on the goal line until the ball is struck. However the goalkeeper is allowed to move horizontally on the goal line. The player is not allowed to pause (fully stand still) during the run-up, but is allowed to slow down in order to trick the goalkeeper.

4.3 Procedure

At the start of the experiment, the participants were asked to fill in a covid-19 health checklist, read the information brochure and sign the informed consent form. The experiment has been approved by the ethics committee of the EEMCS faculty of the University of Twente, with reference number 'RP 2020-118'. The experiment could proceed if the participant had signed the consent form and when the participant passed the health check.

Afterwards the participants filled in a demographic questionnaire, including the Edinburgh Inventory to determine the Laterality Quotient and the SCAT to determine the level of performance anxiety.

When the participants had finished the questionnaire, the fNIRS cap was attached to the participant. Whilst the researcher was verifying the quality of each channel, the structure of the experiment was explained to the participant. An overview of this structure can be found in Figure 4.2. For every round, a rest period was recorded first. The participant was instructed to, during the rest period, try to move and speak as little as possible. Furthermore, the participants were instructed to keep their eyes open and to look in one certain direction, preferably where they could see as little distracting activity as possible. The resting period lasting for 30 seconds each time.

Figure 4.1: Pictures of the experiment, from the front, back and side.

An explanation of the round followed. It was chosen to explain the details of each round after the resting period to make sure that the participants were not thinking/worrying about the upcoming round during the resting period. After the round was explained, the participants were asked how confident they were and how many goals they thought they would score. After placing the ball on the penalty spot and preparing for the run-up, the participants were instructed to wait for 5 seconds, until the researcher indicated that they could kick the ball. The researcher was tracking the time

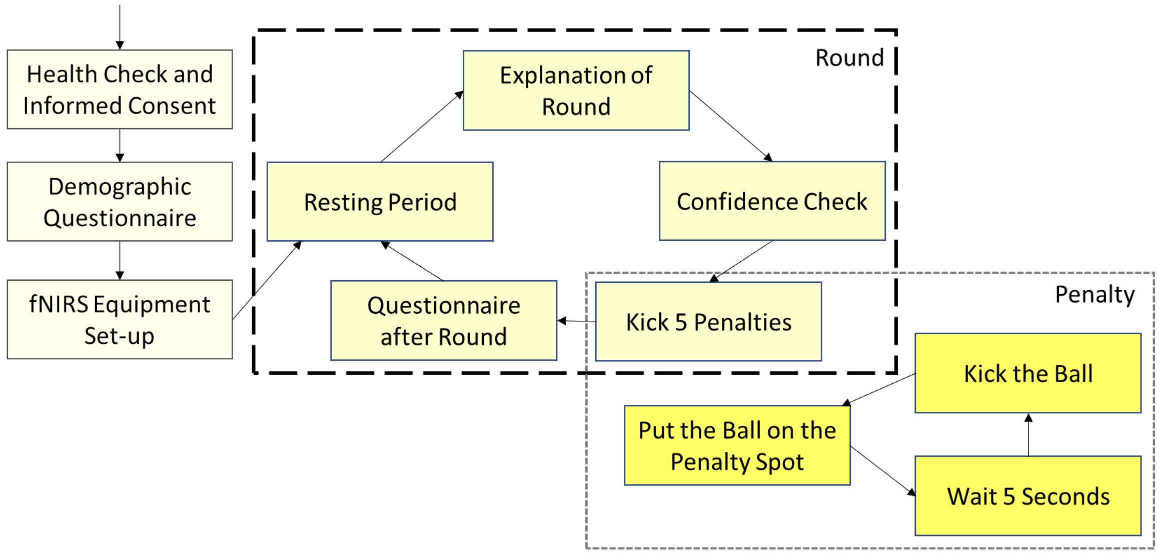

Figure 4.2: Overview of the used procedure. The steps involved before the start of the first round, during a round and during the throw of each dart are shown

by using the build-in stopwatch of the OxySoft software (used for the fNIRS measurement). Using this software, markers were placed during the experiment to indicate the start and end of each 5 second waiting period. These 5 seconds were used for the data analysis, as the player was standing still, minimizing the chances of motion artefacts. The participants were also instructed to minimize body movement during this period. Furthermore, these 5 seconds accompany for the two-second delay of fNIRS signals (see Chapter 2). This 5 second waiting period was included before every kick. When all five penalties were taken, the participant was asked to fill out a small questionnaire. This questionnaire included two 5-point Likert scale questions, regarding the satisfaction about the performance about and the level of motivation during that round. Furthermore, the Sport Anxiety Scale (SAS) was included to determine the level of anxiety/pressure during the round. More information about this questionnaire can be found in Section 4.6. This questionnaire had to be filled in after each round and when the participant was done with the questionnaire, the next round would begin. The fNIRS cap was attached until all three rounds were completed. After the experiment was finished, the participants was explained the purpose of the study and asked what his or her experience was.

In Figure 4.3, an overview of the set-up of the experiment can be found. The participant filled in the questionnaires on a laptop (which was disinfected between each experiment) and the researcher was monitoring the fNIRS signals on a separate laptop. A Sena UD100 Bluetooth adapter[12] was used, which allowed for measurements up to a distance of 300m. This meant that the laptops could be placed at a safe distance from the goal. Furthermore, two GoPro's were used to record the player and the goal.

4.4 Conditions

Whilst doing the experiments, the majority of conditions were kept constant. An artificial football pitch was used to make sure the quality of the pitch was constant for each experiment. Furthermore, all participants were right-handed/footed and of similar age. Every

[12]https://store.netgate.com/Parani-SENA-Bluetooth-Adapter-UD100-G03-P1350.aspx

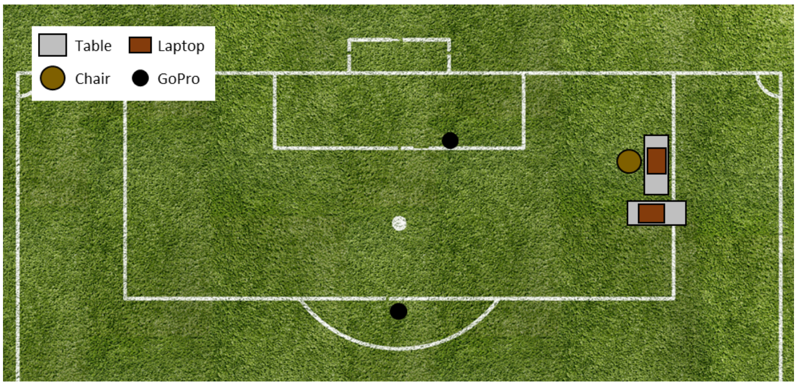

Figure 4.3: Overview of the experiment set-up. The laptop close to the chair was used by the participants to fill in the questionnaires. The GoPro closest to the goal was aimed at the player and the other GoPro at the goal.

participant faced a goalkeeper of the same gender and all goalkeepers were of similar skill level, as they all played in the first team of vv Drienerlo. For all experiments, the same ball was used, namely a Derbystar size 5 (the same ball used in professional matches). For all experiments, the air pressure of the ball was between 0.7 to 0.9 bar, which is according to the professional football guidelines.

As the experiment was done outside, they are also a few conditions that were variable. The weather is an example of such a condition. Temperatures varied between 12 °C and 31 °C and the wind force varied between level 0 (calm) and 4 (moderate breeze) on the Beaufort scale. During three experiments, there was some fog. The experiments were planned from 4 PM to 8 PM (UTC +2 - Dutch timezone during summer), meaning that some experiments were conducted after sunset. During these experiments the light poles of the football pitch were lit. The lights were either off or on during the full experiment, in no case the lights were switched on/off during the experiment.

At last, the number of spectators watching was not constant. During some experiments, no one else was watching, besides the goalkeeper and researcher. However, during some other experiment, around 20 people were around. It is known that being observed by more people can increase the pressure. Therefore this may have an impact on the experienced pressure by the participants.

4.5 Equipment

The Brite 24 developed by Artinis was used for the fNIRS measurements. A sampling rate of 10 Hz was used. The Brite 24 is known as a wireless fNIRS device that can measure brain activity anywhere on the head. The Brite has a total of 10 transmitter optodes and 8 receiver optodes and a numerous amount of templates are available to arrange these optodes. Artinis provides their own software, called OxySoft, to do the measurements and data analysis. All measurement were made using OxySoft, exported to .xlsx data files and analysed using Python. The analysis was done in Python for flexibility and consistency purposes. By using Python, it was certain that the data was analysed exactly as planned. A maximum distance of 30 mm was used between each pair of optodes and a differential pathlength factor (DPF) of 6 was used for all participants.

Two HERO7 GoPro's[13] were used to record videos of the player and the goal during the experiment. The videos were recorded at 60 frames per second and had a quality of 1080p.

4.6 Pressure Induction

The experiment consisted of three rounds and the aim was to increase the pressure per round. In the first round, the lowest amount of pressure should be induced and in the last round the highest pressure should be induced. The specifics of each round were set-up in cooperation with a sports psychologist of the NOC*NSF (the Dutch overarching sports organisation). As a sports psychologist who interacts directly with professional sportsmen and women and (among other things) helps them dealing with pressure, this sports psychologist could be considered as an expert with regard to pressure. Based on the advice and knowledge of the sports psychologist, the rounds were set-up as follows:

1. During the first round, no goalkeeper was present. This means that the player was shooting at an empty goal. Furthermore, the players were told that this round was meant as a practice round. The players could practice their shooting and get used to the procedure of the experiment (e.g. waiting 5 seconds before shooting). By telling the players that this round was meant for practice, the aim was to lower the pressure.

2. During the second round, there was a goalkeeper present, however, the goalkeeper was not allowed to distract the player in any way. Neither the goalkeeper nor the researcher was allowed to respond to the performance of the player. The player was told that in this round, it was just a friendly competition between the player and the goalkeeper and that the aim of this round was to see how well the player could perform against a goalkeeper. By introducing a non-interacting goalkeeper the aim was to introduce the competitive element, without raising the pressure too much.

3. During the last round, the pressure was on. There were namely two 50 euro gift-cards that could be won by the best performing experienced and best performing inexperienced player. This purely depended on how many goals they could score in this round and how well they scored their penalties. During this round, the penalties were taken in a penalty shoot-out way. This means that the player stood around the halfway line (about 40 to 50 meters of the goal) and had to walk with the ball towards the goal. This is also done during professional penalty shoot-outs and it gives the player more time to worry about the penalty. Both the goalkeeper and the researcher tried to distract the player during this round. This was done by trash-talking, by providing (fake) statistics about previous participants ("participant X was way better than you" or "this goalkeeper saved 4 penalties last time, you better be prepared"). When the participant was Dutch, the communication was in Dutch, otherwise the communication was in English. Furthermore, the goalkeeper tried to be more intimidating and annoying this round. This was done by awaiting the player around the penalty spot when the player was approaching the goal from the halfway line, wasting time (by drinking some water or retying their shoelaces), talking to the player when they try to concentrate, call the player by their first name all the time,

[13]https://gopro.com/en/th/shop/hero7-black/tech-specs?pid=CHDHX-701-master

stretch their arms and jump around in order to look bigger and more intimating and by telling the player that they already know where the player is going to shoot the ball. The aim of these actions of the goalkeeper and researcher is to distract the player from their task and focus on something unrelated. Shifting the attention from the centre to an outer circle of Eberspächer's Circles of Attention (see Figure 3.1).

In order to evaluate whether the participant indeed experienced anxiety/pressure, multiple measurements were used.

First, the performance of the players was evaluated each round. This was done by counting how goals were scored and by evaluating the quality of each penalty (placement and power of the shot). A decrease in performance could namely indicate an increase in pressure. In order to obtain this data, one GoPro was used to record the goal, such that the placement and power of the shot could be determined. The power of the shot was defined by the time it took for the ball to reach the goal, this was manually timed using a stopwatch. There are other more advances and accurate method available to measure shot-power. However, as the shot-power statistics were only used to get an indication of the quality of the penalty and the risks taken by the participants (higher shot-power could indicate taking more risks), the current method seems sufficient.

Second, the duration that players looked at the goalkeeper was compared between each round. A longer fixation at the goalkeeper namely means that the goalkeeper is a distracting factor [6, 43, 64]. For consistency reasons, only the fixations during the five-second waiting period were used. As the goalkeeper was only present during the second and third round, this statistic will only be used to compare those two rounds.

Third, before each round, the players were asked how confident they were and how many goals they thought they would score. This is also an indication of how anxious the players are. If a player, for example, thinks that he or she will score all five penalties, this indicates that the player is not experiencing anxiety. On the other hand, if a player answers that he is afraid he won't score many, it is an indication that the player is experiencing some anxiety.

Fourth, after each round, the players filled out the Sport Anxiety Scale (SAS) questionnaire [122–124]. This questionnaire uses a four-point Likert scale, ranging from "not at all" to "very much". Three factors of anxiety are measured, namely somatic anxiety, worry and concentration disruption. The total anxiety was calculated by summing the results from the three factors. The player was considered anxious if one the following conditions was met: 1) the total anxiety score was above or equal to 42, 2) the somatic anxiety score was above or equal to 14, 3) the worry score was above or equal to 10, or 4) the concentration disruption score was above or equal to 18. These scores all correspond to being at least "somewhat" anxious. Besides this questionnaire, the players also indicate how satisfied they were with their performance during that round and how motivated they were to perform.

Last, the heart rate and heart rate variability (HRV) were extracted from the fNIRS signal. It is commonly known that an increased heart rate is related to experiencing anxiety or pressure. Also, HRV has been shown to be related to mental stress, namely a decrease in HRV can be observed during a mentally stressful task as compared to a resting state [108]. Therefore the heart rate and HRV during the 30 second resting period and during the actual activity (from first to last penalty of that round) were compared. An increase in HR and a decrease in HRV would indicate a higher level of pressure. An

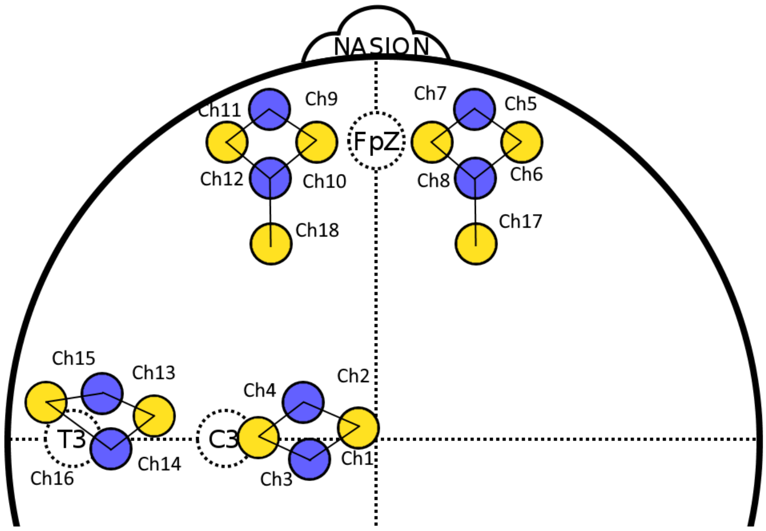

Figure 4.4: Overview of the lay-out of all channels on the scalp. The yellow circles represent transmitter optodes and the blue circles represent receiver optodes. Between each transmitter-receiver pair is a channel. Channel 1 to 4 corresponds to the motor cortex, channels 5 to 8 to the right PFC, channels 9 to 12 to the left PFC and channels 13 to 16 to the left temporal cortex. Channel 17 and channel 18 corresponded to the right and left DLPFC, respectively. Some EEG markers are included and serve as a reference to the optode placement.

explanation about how the heart rate is extracted from the fNIRS signal is given in Section 4.7.2.

4.7 fNIRS Data Analysis

During the experiment fNIRS data was obtained from the following brain regions: left PFC, right PFC, left Temporal Cortex, Motor Cortex, left DLPFC and right DLPFC. In order to measure all of these areas, a '4x4+2' template was used. The optode placement corresponding to this template can be found in Figure 4.4. Four channels were used to record the left PFC, right PFC, left temporal cortex and motor cortex. For both DLPFC regions, one channel was used.

Besides analysing the brain data itself, the heart rate, which can be extracted from clean fNIRS channels, was analysed as well. A channel was considered clean if the presence of artefacts was limited. The heart rate can be used as an indication of pressure (see Section 4.6) and therefore it is of interest to also calculate the heart rate.

At last, in order to get an indication of how well the fNIRS data can be classified, an SVM (Support Vector Machine) was trained and tested for each category. The categories were experienced vs inexperienced players, anxious vs not anxious players and scoring vs missing a penalty. The methods used to pre-process and analyse the fNIRS data in order to obtain reliable brain and heart rate results are explained below. Also the set-up and analysis of the SVM and its classification results are explained below.

4.7.1 Brain Data Analysis

In order to correctly analyse the brain data, the data needed to be pre-processed first. In this section this pre-processing process and the analysis method are described. Every penalty kick is from now on referred to as a trail. As 22 players participated and each participant took 15 penalties, there is a total of 330 trails.

Pre-processing

All channels were pre-processed in the same way. At first the data was filtered using a 5th-order Butterworth-bandpass-filter between 0.02 Hz and 0.5 Hz. Bandpass filtering is a common practice to get rid of physiological noises and drift in optical data [112].

Although fNIRS is relatively robust against motion artefacts, such artefacts can still occur in the signals and need to be compensated for. The motion correction method Temporal Derivative Distribution Repair (TDDR) was used to reduce the impact of motion artefacts on the signals. This novel artefact correction method, developed by Fishburn et al. [115], shows superior performance compared to other correction methods such as Targeted Principle Component Analysis (tPCA) [125] and correlation-based signal improvement (CBSI) [126]. Furthermore, no parameters need to be tuned and only minimal assumptions need to be made about the fNIRS data using this TDDR method. Whilst for other correction methods the fNIRS data needs to be assumed to be normally distributed, this is not the case for the TDDR method. The method was applied for each channel separately, using the following ten steps:

1. The temporal derivative of the channel was computed using Equation 4.1, where x_t represents a datapoint of the fNIRS channel for a certain timepoint (t) and x_{t-1} represents the datapoint of the previous timepoint. By subtracting the data of the previous timepoint from the current datapoint, the change in activity was calculated. All changes between every successive datapoint, represent the temporal derivative and this derivate is represented by y_t.

$$y_t = x_t - x_{t-1} \tag{4.1}$$

2. A vector of observation weight (w) was initialised: $w_t = 1$

3. The weighted mean of the fluctuations (μ) was estimated using:

$$\mu = \frac{1}{\sum(w)} \sum(w_t y_t) \tag{4.2}$$

4. Afterwards the absolute residuals (r_t) of the estimated mean were computed using:

$$r_t = |y_t - \mu| \tag{4.3}$$

5. An estimate of the standard deviation (σ) of these residuals was computed. This was done by multiplying the median absolute residual by the appropriate constant for the normal distribution:

$$\sigma = 1.4826 * median(r) \tag{4.4}$$

6. For each observation the scaled deviation (d_t) was computed. This was done by using the standard deviation of the residuals and the tuning constant that achieves 95% efficiency on normally distributed data:

$$d_t = \frac{r_t}{4.685\sigma} \tag{4.5}$$

7. Tukey's biweight function was used to computed new observation weights:

$$w_t = \begin{cases} (1 - d_t^2)^2 & \text{if } d_t < 1 \\ 0 & \text{otherwise} \end{cases} \tag{4.6}$$

8. Steps 3 to 7 were repeated until μ converged. This was considered the case when the differences between the current μ and the previous μ was smaller than 10^{-50}. If this criterion was not satisfied after a 1000 loops (where one loop is one repetition of steps 3 to 7), the process was stopped. On average 98.75 loops were needed in this process.

9. After μ was converged, the resulting robust weights were applied to the centred temporal derivative (subtracting the mean), in order to produce the corrected derivative ($y_t^{'}$):

$$y_t^{'} = w_t(y_t - \mu) \tag{4.7}$$

10. At last the corrected temporal derivative was integrated in order to obtain the corrected signal ($x_t^{'}$):

$$x_t^{'} = \sum_{i=1}^{N} (y_t^{'}) \tag{4.8}$$

After motion artefacts were removed for each channel, the channels were baselined. At the beginning of every round a 30 second resting period was recorded. This resting period was used as a baseline. The last 15 seconds of the resting period were averaged and this result was subtracted from all datapoints of the signal. This process was done for each channel separately. In Figure 4.5 an example is given of the effects these filter and baseline removal methods on the signals. In this figure the raw signal (before filtering and baseline removal) is plotted against the filtered and baselined signal. As can be seen the presence of the motion artefacts is reduced (sharp peaks) and the physiological noise (rapid fluctuations) were removed.

Certain channels were removed manually, as these channels showed too little activity. These channels were: Ch4 and Ch11, corresponding to the motor cortex and the left PFC, respectively. This was most probably caused due to a bad connection.

Analysing Channels

For the motor cortex and the left temporal cortex, each channel was analysed individually. The total PFC activation and the PFC asymmetry were calculated for each pair of channels. As three channels were related to the left PFC (one channel was manually removed) and four channels were related to the right PFC, there were a total of 12 channel-pairs.

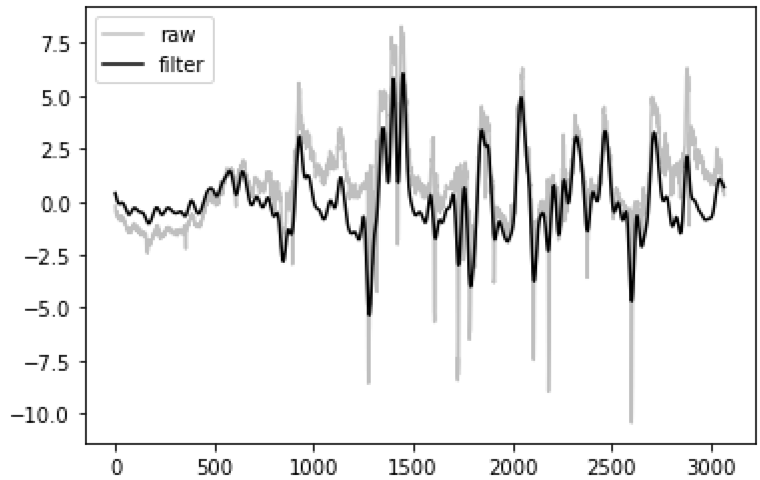

Figure 4.5: Example of the effects of the filter and baseline removal methods on the signal. The raw signal (grey) is plotted against the same signal after filtering and baseline removal (black). The y-axis represents the concentration and the x-axis the datapoints. As the signals were recorded at 10 Hz, every 10 datapoints corresponds to 1 second.

In order to calculate the asymmetry between left and right PFC, the left PFC channel was subtracted from the right PFC channel. This means that a positive asymmetry value corresponds to a higher right PFC activation and a negative value to a higher left PFC activation. When the asymmetry value was close to zero, left and right PFC activation was more symmetrical.

The total PFC was obtained by calculating the average of the left and right PFC channel. This means that the total PFC signal is exactly in between the right and left PFC signals.

As the data of one participant were disproportionately higher than what was expected, the data for this participant was manually removed (all 15 trails). After baseline removal it is expected that the resulting signal has values around 0 and for this particular participant the values were in the hundreds. Potentially something went wrong during the data collection of this participant. Afterwards the mean over all trails was calculated for each channel and outliers (three standard deviation larger or smaller than this mean) were removed.

Furthermore, the data for certain channels of certain trails was removed if the correlation coefficient between the O2Hb signal and the HHb signal was larger than a threshold of $t = 0.4$. Preferably the O2Hb and HHb signal show exact opposite behaviour, as this is an indication that brain activity is actually measured. When the O2Hb and HHb signal show similar behaviour it indicates the presence of motion artefacts. The correlation coefficient is a method to determine these similarities in behaviour. The correlation coefficient ranges from 1 to -1, where positive values indicate similar behaviour between the two signals (i.e. potential motion artefacts). This coefficient was calculated using the correlation coefficient method of the numpy library in Python. A threshold of $t = 0.4$ does not remove all trails with motion artefacts and is therefore not optimal. However, as participants will move during the experiment, motion artefacts are inevitable. Large head movements can already increase the correlation coefficient to 0.1 [126] and jumping to 0.4 [127]. As the movement during the experiment is comparable with jumping, the threshold of $t = 0.4$ seems justified. Furthermore, when comparing the average signals (average of

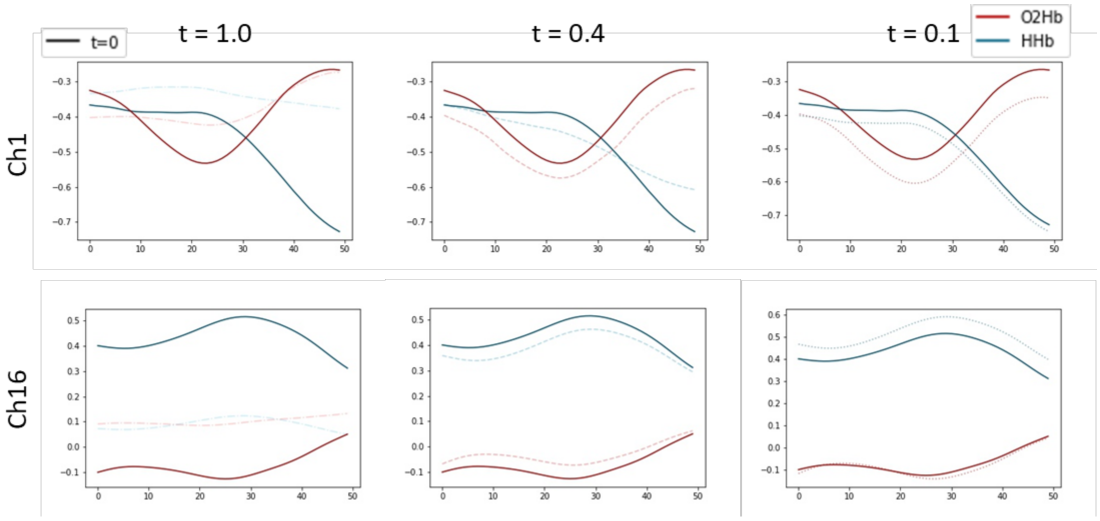

Figure 4.6: Comparison between different correlation coefficient thresholds for the channels 1 and 16. In each plot the optimal threshold of $t = 0.0$ (solid line) is compared to the other thresholds ($t = 1.0$, $t = 0.4$ and $t = 0.1$). All plots show the average result over all trails. Red lines indicate O2Hb-concentrations and the blue lines indicate the HHb-concentrations.

all trails) of each channel for the thresholds $t = 1.0$, $t = 0.4$ and $t = 0.1$ with the most optimal threshold of $t = 0.0$, it can be seen that the signal with threshold $t = 0.4$ shows similar behaviour as the signal with threshold $t = 0.0$ (see Figure 4.6). In this figure the average signals with threshold $t = 1.0$, $t = 0.4$ and $t = 0.1$ are plotted against the average signal with a threshold of $t = 0.0$. This way the different threshold could be compared with the optimal threshold. It can be seen that for a threshold of $t = 1.0$ the resulted signal is very different from the $t = 0.0$ signal. For the other two threshold the results are very similar to the results of the $t = 0.0$ signal. In this figure the results of only two channels were plotted. The results of all channels can be found in Appendix B. The fact that using a threshold of $t = 0.4$ yields similar results as using the optimal threshold of $t = 0.0$ and that around 10% more data remains using this threshold, further justifies the use of this threshold. After removing all channels of all trails with a correlation coefficient larger than 0.4, around 41% of the data remained. This does not (necessarily) mean that all data of certain trails was removed, but rather that the data of certain channels for certain trails were removed.

In order to determine the connectivity between DLPFC and the motor cortex, a similar method as Nguyen et al. [117] was used. First Pearson correlation coefficients (ρ) between every two fNIRS channels were calculated for every trail, using Equation 4.9. In this equation X and Y refer to the channels, σ refers to the standard deviation of that channel and $cov(X, Y)$ to the covariance between the two channels.

$$\rho_{x,y} = \frac{cov(X, Y)}{\sigma_X \sigma_Y} \tag{4.9}$$

Afterwards, these ρ values were transformed to z values using the Fischer z- transformation (see Equation 4.10). This transformation is needed to convert the sampling distribution of the Pearson correlation coefficients into the normal distribution. In this equation ln refers to the natural logarithm.

$$z = \frac{1}{2} ln(\frac{1+\rho}{1-\rho}) \tag{4.10}$$

The number of significant connections was determined by counting the amount connections that had an absolute z-value greater than a threshold of 0.6. A z-value of 0.6 corresponds to a correlation of $\rho \approx 0.54$. The threshold of 0.6 was determined based on the results of Nguyen et al. [117]. They namely found that when using a lower threshold (0.2 to 0.5) almost all connections were classified as significant, whereas when using a higher threshold (0.7), no connections were classified as significant. Based on their results, a threshold of 0.6 seemed most suitable. The strength of the connection between two brain regions was determined by averaging the absolute z-values of all corresponding connections.

Statistical Analysis

In order to test the hypotheses with the obtained data, permutation statistical tests have been used. The advantage of this statistical test is that no assumption needs to be made about the distribution of the data set. Other statistical tests, for example, assume a normally distributed data set. A total of 100,000 permutations were used, meaning that the smallest possible p-value is 10^{-5}.

4.7.2 Heart Rate Extraction

From fNIRS signals, the heart rate can be extracted. In this section, it is explained how the heart rate was extracted from the fNIRS and what methods were used to pre-processes and analyse the data.

Pre-Processing

Not all channels are suitable for heart rate extraction, as some may have too many motion artefacts in order to find a heart rate. Therefore only channels with cardiac components were selected for the heart rate extraction process. In order to find these channels, a similar method as Perdue et al. [128] was used. At first, the power spectral density (PSD) was estimated for each channel, using Welch's method [129]. Afterwards, a Gaussian was fit to each spectrum with the maximum in the power spectrum as the initial guess of the central frequency. This was done using the "*curve_fit*" method of scipy in Python[14]. Channels with Gaussian peaks of more than 1 dB in the range of 1.5 to 3.5 Hz were seen as having sufficient cardiac signal.

Afterwards, sharp and abrupt changes were detected and removed from the sufficient channels. The same method as Peng et al. [130] was used for this process. The abrupt changes were accounted for by removing all datapoints that were 5 $*$ standard deviation above or below the mean. New values were then interpolated using cubic spline interpolation.

The sufficient channels were then filtered, using two first-order zero-phase Butterworth filters. One low-pass of 1.9 Hz and one high-pass filter of 1 Hz were employed. This way the region corresponding to heart rates from 60 beats per minute (BPM) to 114 BPM remains. These filters are exactly the same as the filters used by Mirbagheri et al. [131].

[14]https://docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.curve_fit.html

Afterwards, the signals were upsampled from 10 Hz to 100 Hz, as this has been shown to improve the accuracy in HR estimation [130]. Then the peaks in the signals were detected and the interval between each peak was calculated. Similar to Peng et al. [130] intervals with a length of mean $+ 3 *$ standard deviation were halved.

In order to obtain the heart rates, the interval values were inverted and interpolated to 20 Hz using cubic spline interpolation. The heart rate was then estimated by taking the median heart rate of all channels at each timepoint. The median was chosen over the mean, as the mean could still be influenced by outlier values. At last, the resulted time series was low-pass filtered at 0.3 Hz using a third-order Butterworth filter in forward and backward direction. This procedure to obtain the heart rate from the interval is the same as the procedure used by Peng et al. [130].

Analysing Heart Rate

For every round of every participant, the average heart rate during resting period and activity was calculated. The activity period started when the player prepared to shoot for the first penalty and ended after the fifth penalty was struck. The heart rate is calculated in beats per minute (BPM). Also, the heart rate variability (HRV) during resting period and activity were calculated. The HRV was determined by calculating the standard deviation of all peak intervals (SDNN). The HRV is calculated in milliseconds (ms).

4.7.3 Classifying Brain Data

In order to get an indication of how well the data can be classified, Support Vector Machines (SVMs) were trained and tested. Each category was analysed individually. The categories were experienced and inexperienced players; anxious and not anxious players and scoring and missing a penalty. For each category a separate SVM was trained using the data for each brain region (motor cortex, left temporal cortex, total PFC and PFC asymmetry) in order to be able to compare the results of the different brain regions. This way it can be determined which brain region has the clearest distinction between, for example, experienced and inexperienced players. A higher classification result would namely imply that for that brain region the data is nicely spread, making it easy to classify between the two classes (e.g. experienced and inexperienced).

All channels or channel-pairs of the different brain regions were used. For each channel or channel-pair the mean, standard deviation, the minimum value and the maximum value were calculated and used for the training and testing process of the SVMs. Both the classification results (precision) on the train and test set will be reported. The train set contained 80% of the trails and the test set the remaining 20%. The SVMs were trained and tested five times using the data of a certain brain region for each category, in order to see how consistent the classification results were. The mean and standard deviation of the classification performance of these five runs will be reported. In between each run the data was shuffled. The sklearn library for Python was used to set-up the SVMs. In all cases linear-SVMs were used.

It has been chosen to use SVMs to classify the data, as it has been successfully used before to classify fNIRS data. In the study of Dadgostar et al. [132] a precision of about 87% was achieved using an SVM to classify between people with and without schizophrenia. Although there are other, more advanced, classification methods available that could potentially achieve better results, they are more difficult to implement. As the aim of this study is not to achieve the best classification results possible, but rather to get a first indication of how the well the data is spread and how difficult/easy it is to classify this data, the use of SVMs seems suitable.

Chapter 5

Results

In this chapter, the results of the experiments are shown and analysed. At first, the amount of induced pressure is analysed. Second, the brain results are analysed. The overall activity per round, the difference between experienced and inexperienced players; the difference between scored and missed penalties and the difference between anxious and not anxious players are included, in that order. At last, the SVM classification results are shown.

5.1 Pressure Induction

In order to evaluate if pressure was successfully induced during the experiment, a number of statistics were used. The performance of the players, the time that the players look at the goalkeeper, the confidence of the players before the round, the results of the questionnaire after each round and the heart rate and HRV were analysed in that order.

	Non-Exp	Exp
R1	98.2%	88.0%
R2	25.0%	60.0%
R3	18.3%	62.0%

Table 5.1: Percentage of the penalties that were scored for both experienced and inexperienced players during each round.

When analysing the performance of the players during each round, it can be seen that inexperienced players performed the worst in the last round, whereas experienced players had a similar performance in the second and the last round. The percentage of penalties that were scored in each round (see Table 5.1) demonstrates this.

Overall, experienced players performed better than inexperienced players. Exception is the first round, as experienced players scored less in this round. Inexperienced players took considerably more risks in the later rounds. When looking at the placement (shot-accuracy) of each penalty (see Figure 5.1), it can be seen that during the last round more penalties were shot over or wide by inexperienced players. On average inexperienced players shot their penalties higher and wider per round. Interestingly, this is not the case for experienced players. Although, on average, they also shot their penalties higher, the horizontal placement did not change between the rounds. Furthermore, the shot power for both experienced and inexperienced players increased in the latter rounds. This all indicates that the players took more risks

	Non-Exp	Exp
R2	1.71s	2.82s
R3	3.41s	2.41s

Table 5.2: The duration (out of the 5 second waiting time) that the players were looking at the goalkeeper.

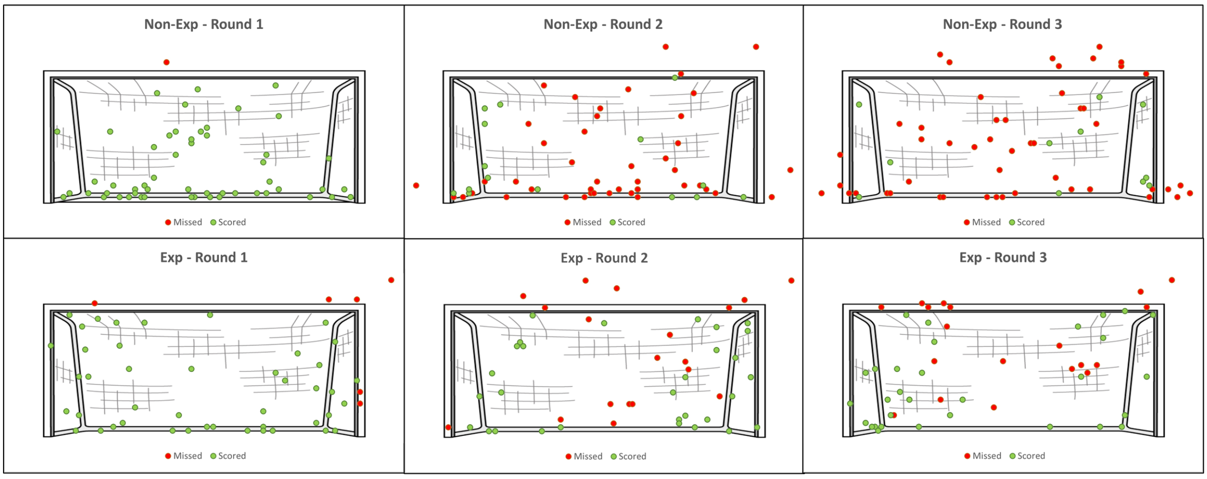

Figure 5.1: Overview of the penalty placement for experienced and experienced players during each round. The first to last column represents the first round to last round. respectively. The first row represents the results of the inexperienced players and the second row of the experienced players. Red dots represent missed penalties and green dots represent scored penalties.

in the last round.

Inexperienced players looked remarkably longer at the goalkeeper during the last round (see Table 5.2). For experienced players, this is not the case. In fact, they looked less at the goalkeeper during the last round. The first round was excluded, as there was no goalkeeper present during this round.

After each round was explained, the players were asked how confident they were and how many goals they thought they would score. On average, players were less confident in the last round, as the expected goals were lower per round. Especially, inexperienced players started to worry about how they would perform in the last round. Experienced players were considerably more confident. Occasionally experienced players were more confident in the last round as compared to the first and second round, although these were exceptions. At the end of the experiments, the players were also asked how much pressure they experienced in each round and the majority indicated that they experienced the most pressure in the last round.

Also, the results of the SAS questionnaire show that the pressure was the highest in the last round. The total anxiety score, worry score and somatic anxiety score were the lowest in the first round and the highest in the last round. The concentration disruption score did not change between the rounds. For 12 out of the 22 participants, the total anxiety score increased per round. During the first round, six participants were considered to be at least "somewhat" anxious. During the second round, this number increased to nine participants and during the last round this number increased to twelve participants. In total, during 135 of the in total 330 trails, the player was at least "somewhat" anxious, which corresponds to 40.9% of the trails. Players that were anxious also missed more penalties (around 58%) than players that were not anxious (around 31%). Furthermore, when looking at Table 5.3, it can be seen that the motivation rating is higher in the second and last round and

	Sat.	Mot.
R1	3.45	3.59
R2	3.45	3.67
R3	2.82	3.67

Table 5.3: Satisfaction and motivation ratings for each round.

	HR Rest	HR Activity	HRV Rest	HRV Activity
R1	108.1	114.5	200.65	183.98
R2	106.7	111.6	186.23	198.21
R3	106.0	113.0	188.21	203.30

Table 5.4: The heart rate (RT) in BPM and heart rate variability (HRV) in milliseconds during rest and activity for each round.

that the satisfaction rating is the lowest in the last round.

When looking at the heart rate (HR) during each round (see Table 5.4) it can be seen that the highest heart rate during rest and during activity (the time period from first to fifth penalty) are observable in the first round. The highest heart rate variability (HRV) at rest was during the first round and highest HRV during activity was during the last round. When comparing the HRV during activity and the HRV during rest, it can be seen that in the last round, this difference is the highest. Only in the first round the HRV during rest is higher than the HRV during activity.

5.2 Overall Activation

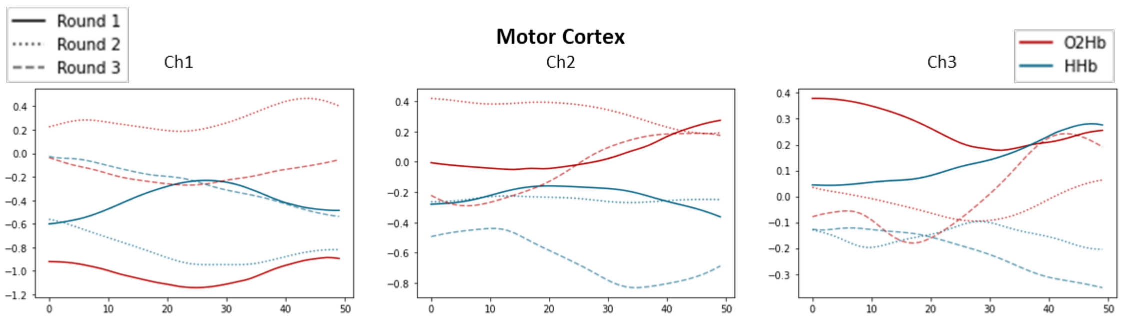

Figure 5.2: Plots corresponding to the average motor cortex activation during each round. The average signal was determined by averaging the results of all trails of that round. From left to right, the channels 1 to 3 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included in each plot. The first round is represented by a solid line; the second round by a dotted line and the last round by a dashed line.

For each brain region of interest (motor cortex, left temporal cortex, total prefrontal cortex (PFC) activation and PFC asymmetry) the activation was compared for each round. Both the HHb and O2Hb concentrations were included for all trails, where the O2Hb concentration is directly related to the activation of a brain area. The O2Hb concentration is namely related to oxygenated hemoglobin. An concentration below zero indicates a lower activation than during the resting period. For the results in this section the trails of both experienced and inexperienced players were used.

For most regions the results were not consistent for each round. Regarding the motor cortex, it can be seen that for one channel the highest activation was found during the second round, whilst for an other channel the first round showed the highest activation (see Figure 5.2). For the first channel the differences between the rounds were most clear, with the lowest activation during the first round and the highest during second round.

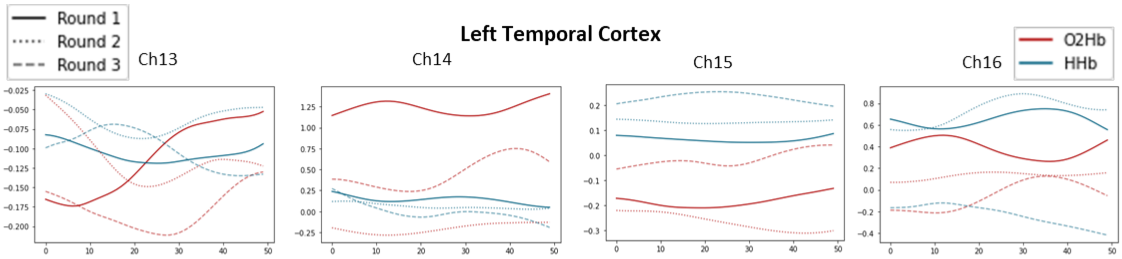

Figure 5.3: Plots corresponding to the average left temporal cortex activation during each round. The average signal was determined by averaging the results of all trails of that round. From left to right, the channels 13 to 16 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included in each plot. The first round is represented by a solid line; the second round by a dotted line and the last round by a dashed line.

Similar results were found regarding the left temporal cortex activation. For two channels the first round was, namely, associated with the highest activation. However, for channel 15 the highest activation was found in the last round (see Figure 5.3). For channel 13 the differences between the rounds were small and therefore the rounds were difficult to distinguish. For channel 14 the differences between the rounds were most clear, with the highest activation found in the first round and the lowest in the second round.

More consistent results were found regarding the total PFC activation. The highest activation was found in the second round for most channel-pairs (see Figure 5.4). In fact, only the channel-pair 7 and channel 12 did not clearly show that the second round was related to the highest activity. In this case, the second and last round had similar total PFC activation results. Regarding the first and last round the results were less consistent, as for half of the channel-pairs the first round had the lowest activation and for the other half this was the case for the last round.

Regarding the asymmetry between left and right PFC activation, again, inconsistent results were found for all rounds. For certain channel-pairs the left PFC was more activated than the right PFC during the first round (indicated by a negative activation), however for other pairs the opposite was observable (see Figure 5.5). For all pairs the left PFC showed a higher activation than the right PFC during the last round.

In Appendix D.1 and D.2 tables can be found related to the plots in this section. The tables contain the means, standard deviations, the minimum values and the maximum values of each plot.

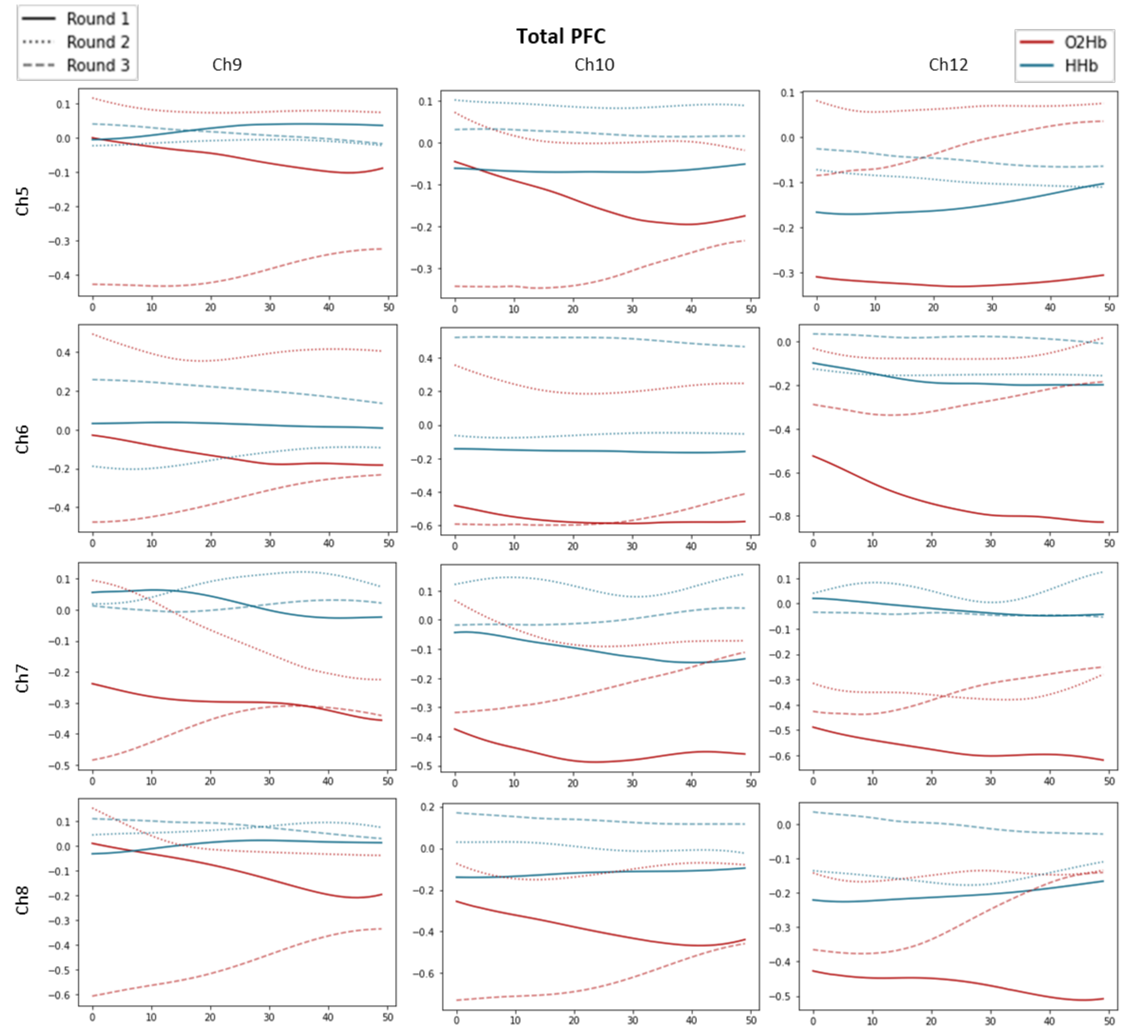

Figure 5.4: Plots corresponding to the average total PFC activation during each round. The average signal was determined by averaging the results of all trails of that round. The columns represent the channels of the left PFC (Ch9, Ch10 and Ch12) and the rows represent the channels of the right PFC (Ch5 to Ch8). Each plot shows the average signal of the channels corresponding to the row and column of that plot. So, the top-left plot represents the average signal of Ch9 and Ch5. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included in each plot. The first round is represented by a solid line; the second round by a dotted line and the last round by a dashed line.

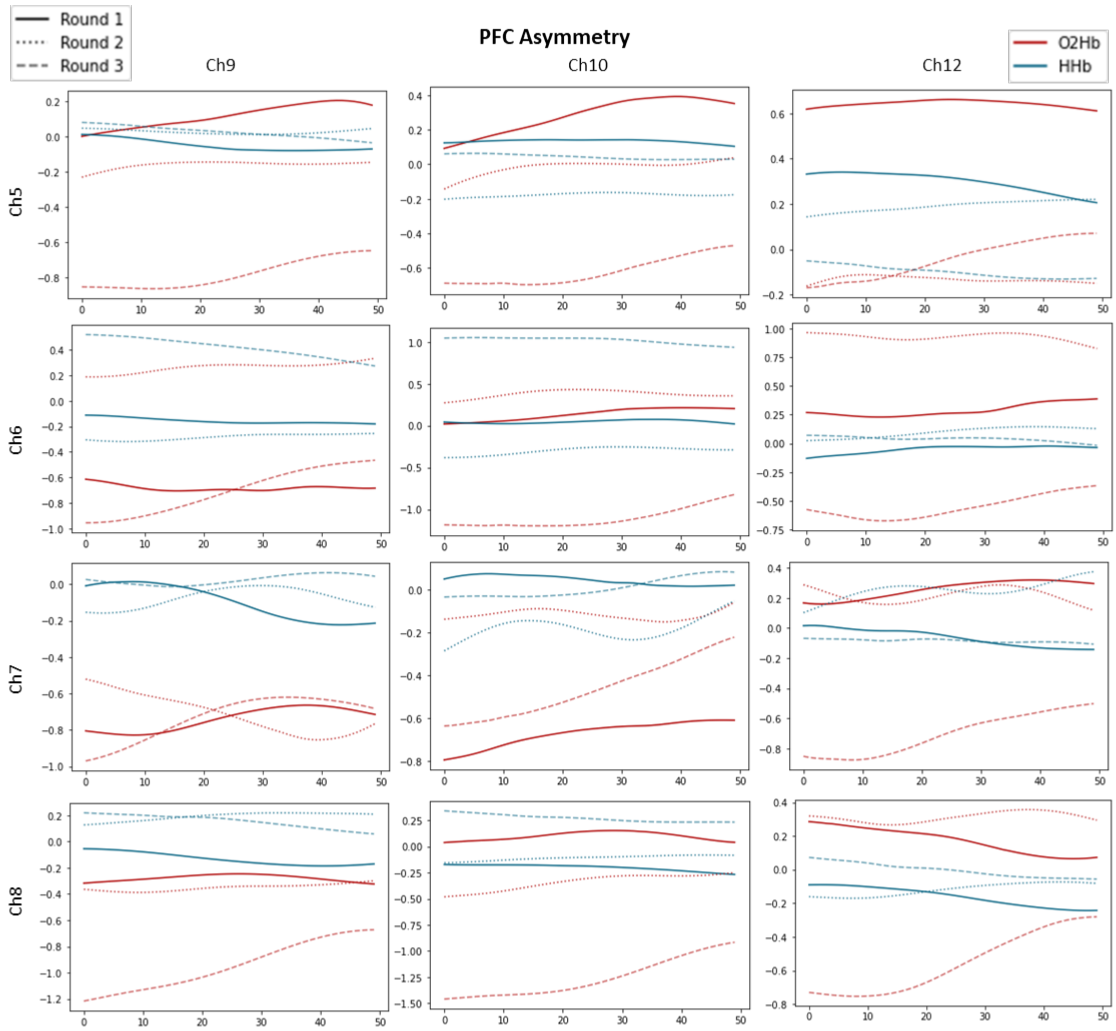

Figure 5.5: Plots corresponding to the average PFC asymmetry activation during each round. The average signal was determined by averaging the results of all trails of that round. The columns represent the channels of the left PFC (Ch9, Ch10 and Ch12) and the rows represent the channels of the right PFC (Ch5 to Ch8). Each plot shows the resulting signal of subtracting the left PFC channel (column) of the right PFC channel (row). So, the top-left plot represents the signal after subtracting Ch9 from Ch5. A positive PFC asymmetry value indicates a higher right as compared to left PFC activation. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included in each plot. The first round is represented by a solid line; the second round by a dotted line and the last round by a dashed line.

5.3 Experienced vs Inexperienced Players

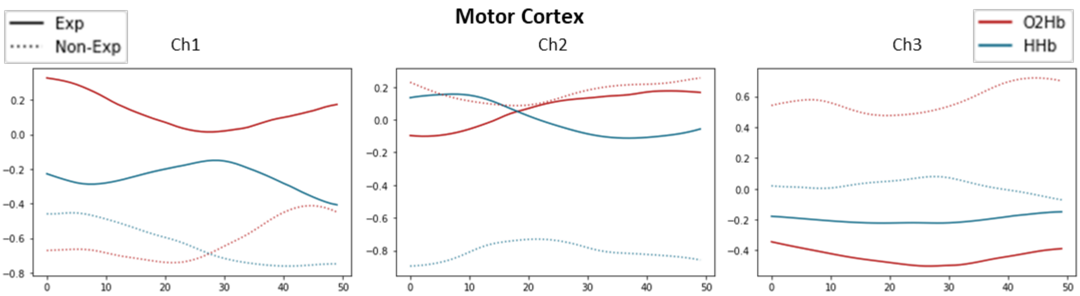

Figure 5.6: Plots corresponding to the average motor cortex activation for experienced and inexperienced players. All trails of experienced or inexperienced players were used to order to obtain these plots. From left to right, the channels 1 to 3 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

The results of experienced and inexperienced players were compared for each brain region of interest. The trails of all rounds were included.

For the motor cortex the results for each channel were different (see Figure 5.6). Regarding the first channel, experienced players showed a higher activation, whilst for the third channel, the inexperienced players showed higher activation. For the second channel, experienced and inexperienced players showed a similar activation.

Regarding the left temporal cortex, the results were more consistent (see Figure 5.7). Namely, for three out of four channels, inexperienced players showed a higher activation than experienced players. The only exception was channel 16. The largest difference between experienced and inexperienced players can be found in channel 14, where inexperienced players showed, on average, an activation twice as high as experienced players.

When looking at the statistical results, it can be seen that none of the channels had a significant results, using $p < 0.05$ (see Table 5.5). For channel 3 the result would be inversely significant.

In this section the results for total PFC activation and the PFC asymmetry were excluded, as no hypotheses were related to these regions and the difference between experienced and non-experienced players (see Section 3.7). The plots for these regions can be

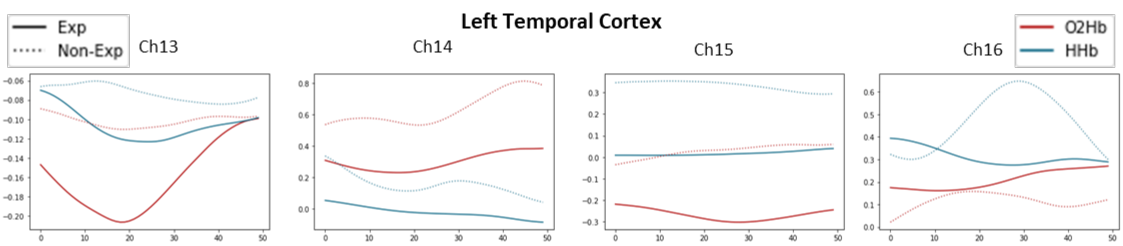

Figure 5.7: Plots corresponding to the average left temporal cortex activation for experienced and inexperienced players. All trails of experienced or inexperienced players were used to order to obtain these plots. From left to right, the channels 13 to 16 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

Brain Area	Channel	Check	P-Value
Left Temporal Cortex	Ch15	Inexperienced players show higher activation	0.05335
Motor Cortex	Ch1	Experienced players show higher activation	0.07045
Left Temporal Cortex	Ch14	Inexperienced players show higher activation	0.19140
Left Temporal Cortex	Ch13	Inexperienced players show higher activation	0.42781
Motor Cortex	Ch2	Experienced players show higher activation	0.62337
Left Temporal Cortex	Ch16	Inexperienced players show higher activation	0.62512
Motor Cortex	Ch3	Experienced players show higher activation	0.99706

Table 5.5: Statistical results of the permutation test regarding experience/expertise. The brain area, channel, check and corresponding p-value are included. No significant results ($p < 0.05$) were found.

found in Appendix C.1. Also plots of the results per round are included in this appendix for all brain regions of interest. In Appendix D.3 tables can be found related to the results of experienced and inexperienced players. These tables contain the means, standard deviations, the minimum values and the maximum values of each plot.

5.4 Anxiety vs No Anxiety

The results of anxious and non-anxious players were compared. For the left temporal cortex experienced and inexperienced players were analysed separately, as the hypotheses suggest that there could be a difference between the two (see Section 3.7). For all other brain regions the trails of experienced and inexperienced players were combined.

For two out of three channels of the motor cortex, a lower activation was related to being anxious (see Figure 5.8). Only in channel 3 the opposite was observable. The difference between anxious and not anxious players was the largest for channel 1, where the motor cortex was clearly less activated for anxious players.

Regarding the left temporal cortex, it can be seen that for three out of four channels, experienced players showed increased activation and inexperienced players showed lowered activation when being anxious (see Figure 5.9). The only exception was channel 14, where experienced players showed lower activation when being anxious and inexperienced players showed similar activation when being anxious or not anxious. For channel 15 the differences between anxious and not anxious players were the largest. Experienced players

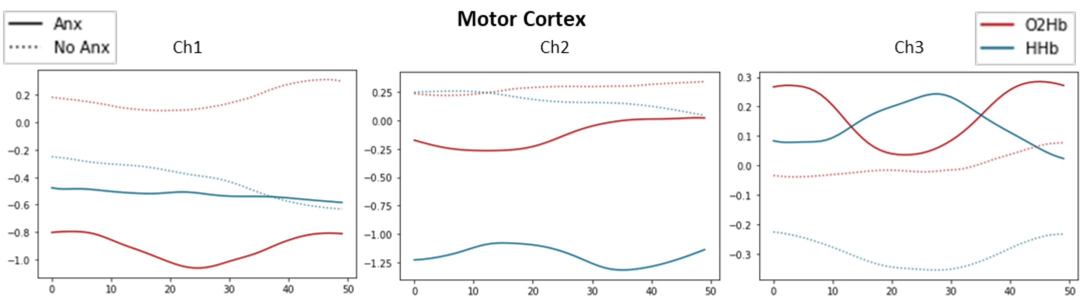

Figure 5.8: Plots corresponding to the average motor cortex activation for anxious and not anxious players. All trails of anxious or not anxious players were used to order to obtain these plots. From left to right, the channels 1 to 3 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

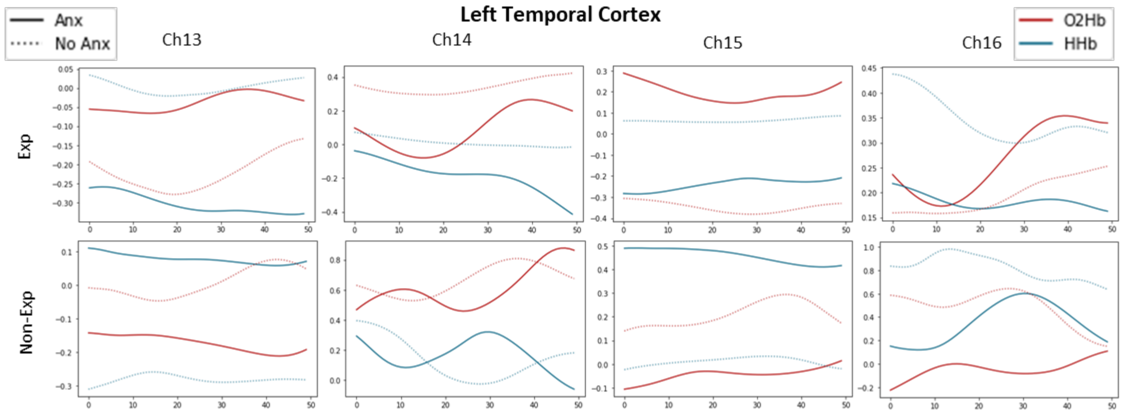

Figure 5.9: Plots corresponding to the average left temporal cortex activation for anxious and not anxious players. All trails of anxious or not anxious players were used to order to obtain these plots. From left to right, the channels 13 to 16 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

showed a clear higher activation and inexperienced a clear lower activation when being anxious.

Also for the total PFC activation the results were consistent. For most channels-pairs the activation was higher for anxious players as compared to not anxious players (see Figure 5.10). The channel-pairs Ch5-Ch9, Ch7-Ch9, Ch8-Ch19 and Ch8-Ch10 showed this higher activation most clearly. Two other pairs showed the complete opposite, namely Ch6-Ch12 and Ch7-Ch12. So, although in general a higher total PFC activation can be associated with anxious players, this was not the case for all channels-pairs.

Most channel-pairs regarding PFC asymmetry showed a higher right compared to left PFC activation whilst being anxious. This was indicated by the evidence that the end result was above 0 (see Figure 5.11). Only the channel pair Ch5-Ch9 showed contradicting results. For this channel-pair the left and right PFC showed similar activation when being anxious. The end result was, namely, around 0.

In Table 5.6 the statistical results are shown. All brain regions of interest were included and for the left temporal cortex experienced and inexperienced players were analysed separately. It can be seen that a few channels had significant results (marked blue). Most of these significant results were related to the total PFC activation, showing that anxious players have an increased activation in this area. The other significant results were related to the motor cortex being less activated when being anxious; the left temporal cortex being more activated for anxious experienced players and a higher right compared to left PFC activation for anxious players. The channel-pair Ch5-Ch9 had an inversely significant result regarding PFC asymmetry ($p > 0.95$). In total 8 out of the 35 results for the analysed channels/channel-pairs were significant.

In this section an selection of the most interesting channels or channel pairs is shown. In Appendix C.2 the plots for all channels/pair of channels can be found. Furthermore, for each brain region results of experienced and inexperienced players are included as well. Tables related to the plots are shown in Appendix D.4. These tables contain the means, standard deviations, the minimum values and the maximum value of each plot.

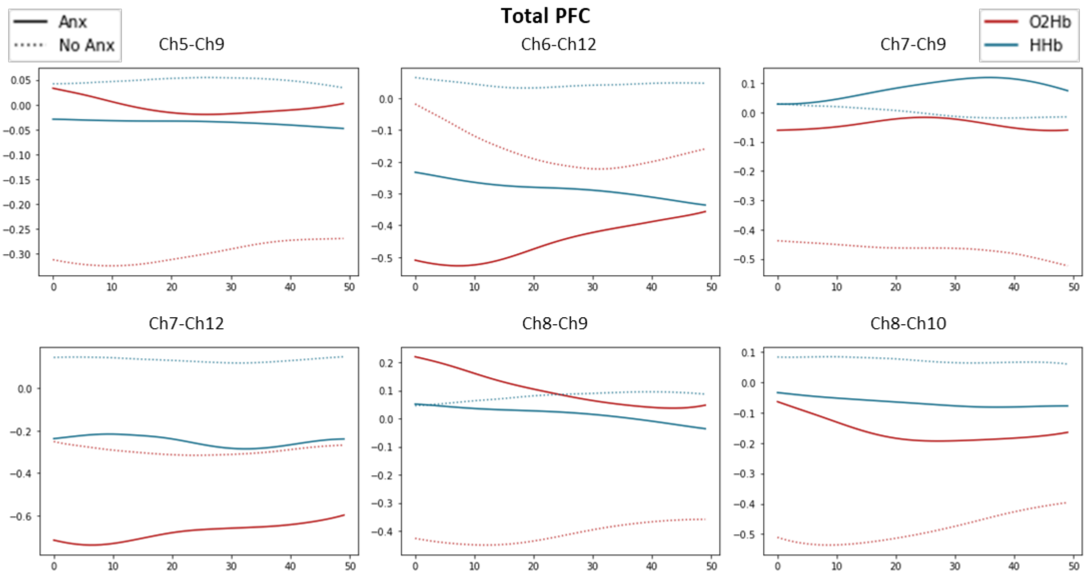

Figure 5.10: Plots corresponding to the average total PFC activation for anxious and not anxious players. All trails of anxious or not anxious players were used to order to obtain these plots. A selection of channel-pairs showing interesting results are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

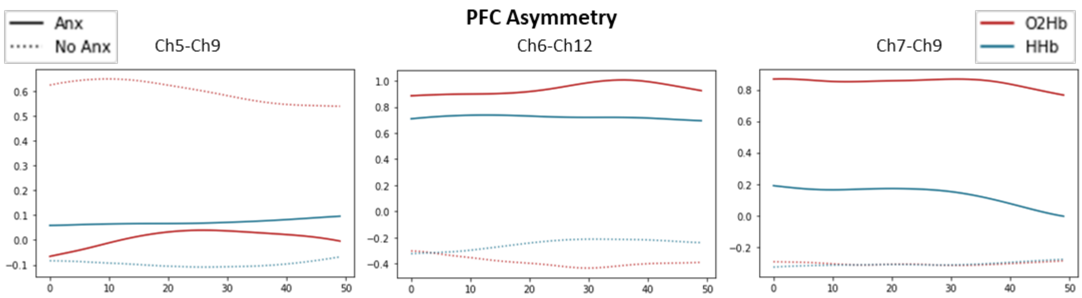

Figure 5.11: Plots corresponding to the average PFC asymmetry activation for anxious and not anxious players. All trails of anxious or not anxious players were used to order to obtain these plots. A selection of channel-pairs showing interesting results are included. A positive asymmetry value, indicates a higher right as compared to left PFC activation. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

5.5 Goal vs No Goal

The results of performing and failing were compared. Scoring a goal was in this case considered as performing and missing as failing. Again, for the left temporal cortex the results for experienced and inexperienced were analysed separately, as it was hypothesised that there could be a difference the two (see Section 3.7). For all the other brain regions the trails of experienced and inexperienced were combined.

For all channels of the motor cortex, it can be seen that the region was more activated when scoring (see Figure 5.12). For the second channel this difference was the largest. For the other two channels this difference was smaller. Yet, it can be seen that the results

Brain Area	Channel	Check	P-Value
Total PFC	Ch8-Ch9	Anxious players show higher activation	0.00105
Total PFC	Ch8-Ch10	Anxious players show higher activation	0.00627
PFC Asymmetry	Ch6-Ch12	Anxious players show higher right compared to left PFC activation	0.00921
PFC Asymmetry	Ch8-Ch12	Anxious players show higher right compared to left PFC activation	0.01639
Motor Cortex	Ch1	Anxious players show lower activation	0.01700
Left Temporal Cortex	Ch15	Anxious experienced players show higher activation	0.04260
Total PFC	Ch5-Ch9	Anxious players show higher activation	0.04335
Total PFC	Ch7-Ch9	Anxious players show higher activation	0.04824
Motor Cortex	Ch2	Anxious players show lower activation	0.10193
PFC Asymmetry	Ch7-Ch10	Anxious players show higher right compared to left PFC activation	0.12055
Left Temporal Cortex	Ch16	Anxious inexperienced players show lower activation	0.14043
PFC Asymmetry	Ch5-Ch12	Anxious players show higher right compared to left PFC activation	0.14333
PFC Asymmetry	Ch5-Ch10	Anxious players show higher right compared to left PFC activation	0.18116
Left Temporal Cortex	Ch15	Anxious inexperienced players show lower activation	0.21172
PFC Asymmetry	Ch6-Ch9	Anxious players show higher right compared to left PFC activation	0.23723
PFC Asymmetry	Ch7-Ch12	Anxious players show higher right compared to left PFC activation	0.25147
Left Temporal Cortex	Ch13	Anxious experienced players show higher activation	0.29318
PFC Asymmetry	Ch6-Ch10	Anxious players show higher right compared to left PFC activation	0.34479
PFC Asymmetry	Ch7-Ch9	Anxious players show higher right compared to left PFC activation	0.37269
Left Temporal Cortex	Ch13	Anxious inexperienced players show lower activation	0.37288
Left Temporal Cortex	Ch16	Anxious experienced players show higher activation	0.44481
Left Temporal Cortex	Ch14	Anxious inexperienced players show lower activation	0.46440
PFC Asymmetry	Ch8-Ch10	Anxious players show higher right compared to left PFC activation	0.50015
Total PFC	Ch6-Ch10	Anxious players show higher activation	0.51918
Total PFC	Ch7-Ch10	Anxious players show higher activation	0.53264
Total PFC	Ch6-Ch9	Anxious players show higher activation	0.57357
Left Temporal Cortex	Ch14	Anxious experienced players show higher activation	0.64048
Motor Cortex	Ch3	Anxious players show lower activation	0.67550
Total PFC	Ch8-Ch12	Anxious players show higher activation	0.72585
Total PFC	Ch6-Ch12	Anxious players show higher activation	0.79877
Total PFC	Ch5-Ch10	Anxious players show higher activation	0.81720
Total PFC	Ch5-Ch12	Anxious players show higher activation	0.85749
PFC Asymmetry	Ch8-Ch9	Anxious players show higher right compared to left PFC activation	0.87602
Total PFC	Ch7-Ch12	Anxious players show higher activation	0.92712
PFC Asymmetry	Ch5-Ch9	Anxious players show higher right compared to left PFC activation	0.95799

Table 5.6: Statistical results of the permutation test regarding anxiety. The brain region, channel/channel-pair, check and the corresponding p-value are included. The blue-marked rows represent significant results ($p < 0.05$).

were consistent for all channels of the motor cortex.

Less consistent results were found regarding the left temporal cortex (see Figure 5.13). When looking at the results of experienced players it can be seen that for three out of four channels a higher activation was related to scoring. Channel 15 was the exception, as the opposite was observable for this channel. For inexperienced players, different results were found. For channel 15 and channel 16, the difference between scoring and missing was small. For channel 13, scoring was associated with lowered activation and for channel 14 the opposite was observable.

Regarding the total prefrontal cortex (PFC) activation, it can be seen that for most channel-pairs the region was more activated when scoring (see Figure 5.14). An exception was the channel-pair Ch8-Ch12, as here a lower activation was related to scoring. This was opposite of what was expected, as a higher PFC activation was hypothesised to be related to missing a penalty.

More consistent results were found regarding the asymmetry between left and right PFC (see Figure 5.15). For most channel-pairs a higher right compared to left PFC activation (positive asymmetry) was related to missing. One of the exceptions was the channel-pair Ch7-Ch12, as a higher left compared to right PFC activation was here related to missing a penalty.

In Table 5.7 the statistical results regarding scoring and missing can be found. It can be seen that for three channels/channel-pairs the result was significant (marked blue). Two

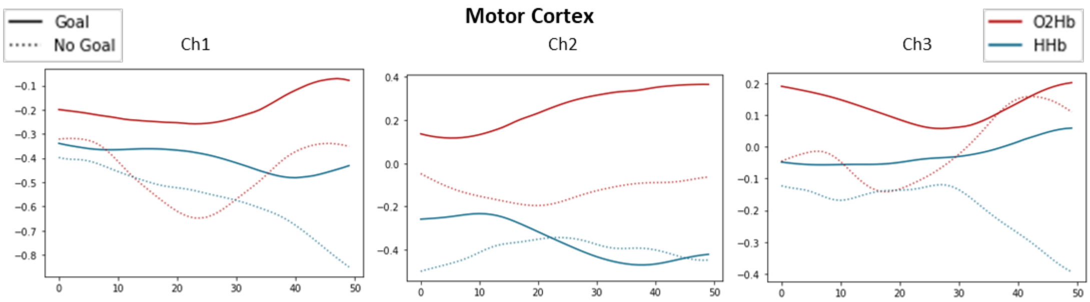

Figure 5.12: Plots corresponding to the average motor cortex activation for scoring and missing penalties. All trails of scored and missed penalties were used to order to obtain these plots. From left to right, the channels 1 to 3 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scored penalties are represented by a solid line and missed penalties by a dotted line.

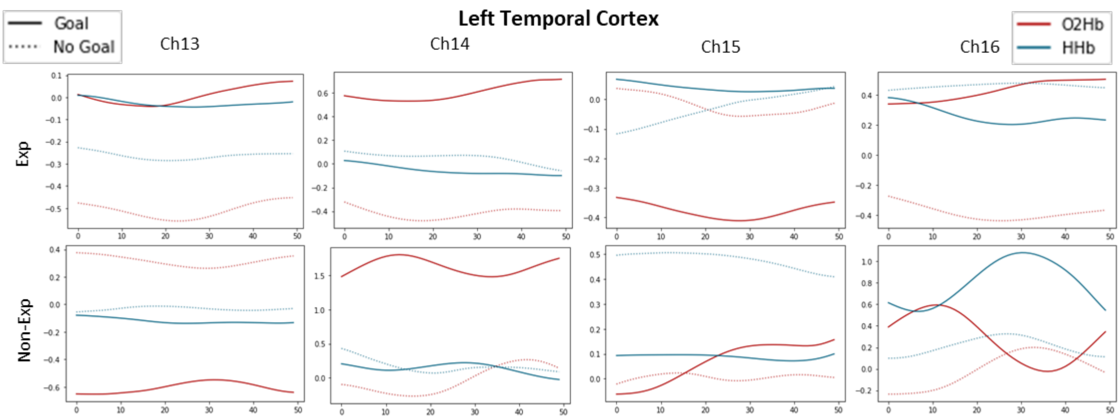

Figure 5.13: Plots corresponding to the average left temporal cortex activation for scoring and missing penalties. All trails of scored and missed penalties were used to order to obtain these plots. From left to right, the channels 13 to 16 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scored penalties are represented by a solid line and missed penalties by a dotted line.

of these results were related to the PFC asymmetry and the other to the left temporal cortex. These results state that: a higher right compared to left PFC activation was related to missing and that inexperienced players showed an increased left temporal cortex activation when scoring. A total of 5 results would be inversely significant ($p > 0.95$). Three of these results were related to the left temporal cortex and the other two to the total PFC activation.

Again, only the plots of the most interesting channels are shown in this section. In Appendix C.3 the plots for all channels of channel-pairs can be found. Furthermore, plots for both experienced and inexperienced are included for all brain regions of interest. Tables related to the plots are shown in Appendix D.5. These tables contain the means, standard deviations, the minimum values and the maximum values of each plot.

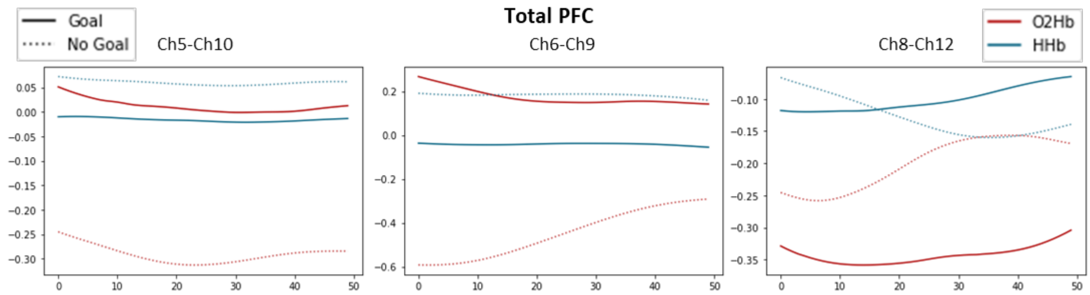

Figure 5.14: Plots corresponding to the average total PFC activation for scoring and missing penalties. All trails of scored and missed penalties were used to order to obtain these plots. A selection of channel-pairs showing interesting results are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scored penalties are represented by a solid line and missed penalties by a dotted line.

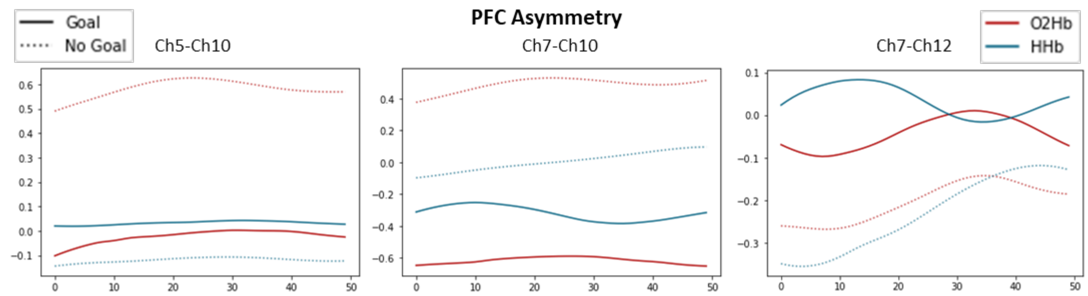

Figure 5.15: Plots corresponding to the average PFC asymmetry activation for scoring and missing penalties. All trails of scored and missed penalties were used to order to obtain these plots. A selection of channel-pairs showing interesting results are included. A positive asymmetry value, indicates a higher right as compared to left PFC activation. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scored penalties are represented by a solid line and missed penalties by a dotted line.

5.6 DLPFC-Motor Cortex Connectivity

A larger connectivity between the motor cortex and the dorsolateral prefrontal cortex (DLPFC) was hypothesised to be related to performing under pressure. The connectivity (z-value) between each channel-pair of the motor cortex and the DLPFC was calculated and based on that connectivity value, the number of connected channels was counted. Every channel-pair with an z-value over 0.6 was considered to be connected. The connectivity was determined for two conditions: scoring/missing when being anxious and scoring/missing during the last round.

For anxious players that still manage to score, both the average z-value and number of connected channels were larger. The average z-values were: when scoring $z = 0.935$ and when missing $z = 0.811$. The number of connections increased by 5.7% when scoring, from 48.7% to 54.4%.

When only considering trails during the last round (highest pressure round) these difference were larger. When scoring, the average z-value was $z = 1.061$, whilst when missing, this value was smaller: $z = 0.831$. The number of connected channels increased by 16.3% when scoring during the last round. When missing the percentage of connected channels was 50.5% and when scoring this increased to 66.8%.

Brain Area	Channel	Check	P-Value
PFC Asymmetry	Ch7-Ch10	A higher left compared to right PFC activation is related to scoring	0.00050
Left Temporal Cortex	Ch14	Inexperienced players show increased activation when scoring	0.00132
PFC Asymmetry	Ch5-Ch10	A higher left compared to right PFC activation is related to scoring	0.03885
Left Temporal Cortex	Ch15	Experienced players show decreased activation when scoring	0.07384
PFC Asymmetry	Ch8-Ch12	A higher left compared to right PFC activation is related to scoring	0.11600
Motor Cortex	Ch2	A higher activation is related to scoring	0.12590
PFC Asymmetry	Ch7-Ch9	A higher left compared to right PFC activation is related to scoring	0.13717
PFC Asymmetry	Ch6-Ch9	A higher left compared to right PFC activation is related to scoring	0.15082
PFC Asymmetry	Ch6-Ch10	A higher left compared to right PFC activation is related to scoring	0.17817
PFC Asymmetry	Ch5-Ch9	A higher left compared to right PFC activation is related to scoring	0.20863
Total PFC	Ch8-Ch12	A lower activation is related to scoring	0.23270
Left Temporal Cortex	Ch16	Inexperienced players show increased activation when scoring	0.26079
PFC Asymmetry	Ch8-Ch10	A higher left compared to right PFC activation is related to scoring	0.29182
Motor Cortex	Ch1	A higher activation is related to scoring	0.30604
Motor Cortex	Ch3	A higher activation is related to scoring	0.37438
PFC Asymmetry	Ch8-Ch9	A higher left compared to right PFC activation is related to scoring	0.41174
Left Temporal Cortex	Ch15	Inexperienced players show increased activation when scoring	0.41543
Total PFC	Ch8-Ch10	A lower activation is related to scoring	0.44278
PFC Asymmetry	Ch5-Ch12	A higher left compared to right PFC activation is related to scoring	0.46034
Total PFC	Ch8-Ch9	A lower activation is related to scoring	0.53572
Total PFC	Ch5-Ch12	A lower activation is related to scoring	0.53678
PFC Asymmetry	Ch6-Ch12	A higher left compared to right PFC activation is related to scoring	0.62745
Total PFC	Ch7-Ch12	A lower activation is related to scoring	0.63113
Total PFC	Ch7-Ch9	A lower activation is related to scoring	0.64575
PFC Asymmetry	Ch7-Ch12	A higher left compared to right PFC activation is related to scoring	0.66142
Total PFC	Ch7-Ch10	A lower activation is related to scoring	0.67113
Total PFC	Ch6-Ch12	A lower activation is related to scoring	0.74772
Total PFC	Ch5-Ch9	A lower activation is related to scoring	0.78992
Total PFC	Ch6-Ch10	A lower activation is related to scoring	0.85460
Left Temporal Cortex	Ch13	Experienced players show decreased activation when scoring	0.93680
Left Temporal Cortex	Ch13	Inexperienced players show increased activation when scoring	0.95745
Total PFC	Ch5-Ch10	A lower activation is related to scoring	0.96146
Left Temporal Cortex	Ch16	Experienced players show decreased activation when scoring	0.97054
Left Temporal Cortex	Ch14	Experienced players show decreased activation when scoring	0.98921
Total PFC	Ch6-Ch9	A lower activation is related to scoring	0.99085

Table 5.7: Statistical results of the permutation test regarding scoring and missing. The brain region, channel/channel-pair, check and the corresponding p-value included. The blue-marked rows represent significant results ($p < 0.05$).

When looking at the statistical results (see Table 5.8) it can be seen that there were no significant results regarding connectivity. Although all results showed that a higher connectivity was related to performing under pressure, none of these results was significant. Having a higher number of connected channels when scoring, during the last round was the closest to being significant, with a p-value slightly above 0.05.

Variable	Check	Result
Number of connections	More connections when scoring during last round	0.05136
Connectivity z-value	Higher connectivity when scoring during last round	0.09707
Connectivity z-value	Higher connectivity when scoring when anxious	0.21843
Number of connections	More connections when scoring when anxious	0.25582

Table 5.8: Statistical results of the permutation test regarding the motor cortex-DLPFC connectivity. The variable, check and corresponding p-value are included. No significant results were found ($p < 0.05$).

	Exp/Non-Exp		Anx/No Anx		Goal/No Goal	
	Train	Test	Train	Test	Train	Test
Motor Cortex	79.7% (± 1.4)	63.6% (± 7.2)	77.4% (± 1.3)	61.0% (± 5.7)	76.4% (± 3.1)	53.4% (± 8.5)
Left Temp.	71.1% (± 1.2)	58.4% (± 3.7)	74.4% (± 1.2)	64.0% (± 4.9)	67.6% (± 2.2)	54.8% (± 10.2)
Total PFC	78.4% (± 2.0)	57.9% (± 4.2)	76.9% (± 3.1)	64.1% (± 4.9)	72.4% (± 1.1)	61.5% (± 4.3)
PFC Asym.	79.9% (± 0.9)	61.0% (± 4.1)	74.2% (± 1.3)	57.4% (± 5.0)	74.7% (± 0.9)	63.1% (± 5.5)

Table 5.9: SVM classifier results (precision). The average and the standard deviation of the classification performance of the five runs is shown (in percentages). For each category (experienced vs inexperienced; anxiety vs no anxiety and scoring vs missing) an SVM was trained and tested five times using the data corresponding to one brain region (column).

5.7 Classifier Results

In order to research how well the data could be classified for each category (experience, scoring and anxiety), SVMs (Support Vector Machines) were trained and tested. At all times an SVM was trained and tested five times, randomizing the data-set (containing the trails of all participants). The mean classification result and standard deviation were determined, based on these five runs. The standard deviation gives an indication of the consistency of the classification results between the five runs. These results can be found in Table 5.9. In this table both the classification results on the train and the test set are shown. The train-set contained 80% of the data and the test-set contained 20%.

It can be seen that in all cases the classification results were better on the train-set than on the test-set. The best result on the train-set was obtained by using the channel-pairs related to prefrontal cortex (PFC) asymmetry, to distinguish between experienced and inexperienced players. The best result on the test-set was obtained by using the channel-pairs related to the total PFC activation, to distinguish between anxious and not anxious players.

When only considering the results on the test-set, it can be seen that, using the motor cortex data, it was easiest to distinguish between experienced and inexperienced players. When looking at the differences between anxious and not anxious players, the data related to total PFC activation and left temporal cortex activation showed the best results. Both had a similar classification result (precision) of around 64%. At last, in order to distinguish between scoring and missing, the channels related to PFC asymmetry showed the best result.

In all cases the classification results were above chance. As there were in all cases two conditions (e.g. experienced or inexperienced), the chance level was at 50%. The lowest classification results were close to this chance level. These results, namely, were 53.4% and 54.8% and were related to classifying between scoring and missing using the data of the motor cortex and the left temporal cortex, respectively. The standard deviation of these classification results was also the largest (8.5% and 10.2%), meaning that in certain runs the results was below chance.

Chapter 6

Discussion

During this study, the brain activity of different regions was measured using fNIRS during a penalty kick task. The experiment consisted of three different rounds, where the aim was to increase the pressure per round. In this chapter, these results are discussed and used to reflect on the set-up hypotheses (see Chapter 3.7).

6.1 Successful Pressure Induction

Looking at the results used to measure pressure induction, it can be seen that pressure was successfully induced (see Section 5.1). Especially, inexperienced players seem to have experienced an increasing level of pressure. First, both experienced and inexperienced players took more risks in the later rounds. This can be shown by the evidence that the shot power and the vertical placement increased. For inexperienced players, penalties were also shot wider in the last round (see Figure 5.1). Other factors could have also had an influence on this. In the last round, the players were namely competing for a prize and in order to win this prize, they had to not only score the most goals, but also the best quality goals. This could have influenced them to take more risks in the last round (e.g. trying to shoot the ball in the top corner).

Second, a decrease in performance for inexperienced players was observable between the second and last round (see Table 5.1). Although this could be an indication of an increased level of pressure, it could also be explained by the fact that the players had already taken five penalties against the goalkeeper. Based on these five penalties, the goalkeeper could potentially already know what the shooting technique and favourite corner of the player would be. For experienced players, this decrease in performance was not observable. In fact, they performed slightly better in the last round as compared to the second round. Some experienced players indicated that they needed some kind of pressure in order to perform, which could be an explanation of this slight increase in performance.

Third, the goalkeeper was a larger distracting factor for inexperienced players in the last round. This shows itself in a longer fixation at the goalkeeper (see Table 5.2). The aim was to distract the player in the last round and this tactic seems to have been successful for inexperienced players. Again, this does not seem the case for experienced players, as they fixated for a shorter period of time at the goalkeeper during the last round. This can be explained by the fact that experienced players are more familiar with these distracting methods of a goalkeeper and therefore know how to keep their concentration under these circumstances.

Fourth, both experienced and inexperienced players were less confident about their performance before the last round. This was especially the case for inexperienced players. Some inexperienced players were visually worried after the last round was explained.

Fifth, the results of the Sport Anxiety Scale (SAS) questionnaire show that the pressure was the highest in the last round. Most components of this questionnaire (total anxiety score, worry score and somatic anxiety score) were the lowest in the first and the highest in the last round. The concentration disruption score did not alter between the rounds. Furthermore, the nuber of participants that could be classified as being at least "somewhat" anxious was the highest in the last round and the lowest in the first round. This was the case for both experienced and inexperienced players. As anxious players performed worse (more misses), it can be assumed that the results of the SAS questionnaire are trustworthy. Anxious players are more likely to miss [6].

Interestingly the heart rate results do not correspond with the previous findings. Namely, according to the heart rate results, the pressure was the highest in the first round. The average heart rate during the execution of the penalty kicks was the highest and the heart rate variability (HRV) was the lowest during the first round (see Table 5.4). The heart rate was extracted from the fNIRS signal and could have therefore potentially been influenced by motion artefacts. For future research, it is advised to use an external heart rate detector, such as a smartwatch, in order to obtain reliable heart rate data.

Overall, it can therefore be concluded that pressure was successfully induced. Most measurements related to the pressure induction namely point into that direction. The distribution between anxious and not anxious players is also nicely balanced (41% to 59%).

6.2 Results in Line with Neural Efficiency Theory

When looking at the results related to brain activity it can be seen that they were mostly in line with the Neural Efficiency theory. When being anxious the motor cortex (task-relevant area) was namely activated less for two out of three channels (see Figure 5.8). For the first channel this result was significant as well (see Table 5.6). Also when scoring a penalty (performing) the motor cortex was more activated than when missing a penalty (failing to perform), although for no channel this result could be considered significant (see Figure 5.12 and Table 5.7). These results support the fifth and sixth hypothesis (H5 and H6), which stated that "*The motor cortex is less activated when being anxious*" and "*The motor cortex is more activated when scoring a penalty*", respectively.

The activation of task-irrelevant areas of the brain was more common when being anxious. This was most prominently observable in the prefrontal cortex (PFC), as an increase in total PFC activation was related to being more anxious (see Figure 5.10). For 4 channel-pairs, this result was significant as well (see Table 5.6). These results are in line with the theories of Korb, Nosrati et al. and Schweizer et al. [7, 84, 85], as they state that an overactivation of the PFC would be related to choking under pressure. According to Korb [7] this overactivation would cause a distraction, decreasing one's focus on the task. The results of this study agree with that, as an increase in PFC activation was paired with a decrease in motor cortex activation when being anxious. The long-term thinking element of the PFC could be the source of this distraction, as players might think about the consequences of missing or scoring the penalty [7]. These results support the first hypothesis (H1), which stated that "*The PFC is more activated when being anxious*".

Besides this increase in total PFC activation, the anxiety level of the player was also observable in the difference between left and right PFC activation. For most channel-pairs the right PFC was more activated compared to the left PFC for anxious players (see Figure 5.11). For some channel-pairs this result was significant as well (see Table 5.6).This is in line with the theories of Hatfield and Kerick, Meyer et al. and Silveira et al. [21, 91, 92], as they stated that a more symmetrical PFC activation (caused by a stronger right PFC activation) leads to choking under pressure. Furthermore, these results are in support of the fourth hypothesis (H4), which stated that "*The PFC activation is more symmetrical (stronger right PFC activation) when being anxious*".

This could be an indication that the increase in total PFC activation for anxious players was caused by an increase in mostly the right PFC. However, as no significant results were found regarding the increase in total PFC activation and the increase of right compared to left PFC activation for the same channel-pair, these conclusions cannot be made directly. When looking at the statistical results of Table 5.6, it can be seen that for no channel-pair both the total PFC and PFC asymmetry result were significant. In fact, the opposite was observable. When the total PFC result had a low p-value for a certain channel-pair, the PFC asymmetry result had a rather large p-value. For example, for the channel-pair Ch8-Ch9 the total PFC result had a p-value of $p = 0.00105$ and the PFC asymmetry result had a p-value of $p = 0.87602$. This shows that there was no indication that the increase in total PFC activation for anxious players was caused by an increase in mostly right PFC activation.

For experienced players an increased activation of the left temporal cortex was linked with being anxious. Namely, for three out of four channels, the left temporal cortex was more activated when experienced players were anxious (see Figure 5.9). For channel 15 this results was also significant (see Table 5.6). For inexperienced players the opposite was observable, as a decrease in left temporal activation was associated with being anxious (see Figure 5.9). Again, three out of four channel show this behaviour, however in this case no significant results were found (see Table 5.6). For both experienced and inexperienced players channel 14 was the exception, as for this channel opposing results were found compared to the other three channels. These results are in line with the theories of Wolf et al. [11] and Zhu et al. [78]. According to these studies, the left temporal cortex' relationship to self-instruction and self-reflecting is an explanation, as it can cause a distraction for experienced players. Experienced should namely trust on their automated skills and therefore do need to instruct or reflect themselves less. Self-instruction and self-reflection are namely essential skills in the early stages of learning a motor skill [11]. By activating the left temporal cortex more, experienced players neglect their automated skills and start to "overthink" the situation. For inexperienced players the opposite is observable. As these players do not have the automated skills yet, an increase in left temporal cortex activation should be beneficial for their performance. They still need to learn the skill. This could be an explanation for the fact that inexperienced players showed a decrease in left temporal cortex activation when being anxious, they might forget to instruct themselves in order to learn and get better. So, for inexperienced players an increase in activation in this area is beneficial and for experienced players this increase can be seen as a distracting factor. These results support the eleventh and twelfth hypothesis (H11 and H12), which stated that "*Experienced players show a higher left temporal activation when being anxious*" and "*Inexperienced players show a lower left temporal activation when being anxious*", respectively.

The fact that the left temporal cortex is related to procedures beneficial for the early stages of learning a motor skill, also explains why inexperienced players showed a higher activation in this brain region than experienced players. This is the case for three out of the four channels related to the left temporal cortex (see Figure 5.7). Although none of these results were significant (see Table 5.5), they are still in line with numerous previous studies [11, 72, 73, 80–83, 106, 107]. These results support the tenth hypothesis (H10), which stated that "*Inexperienced players show a stronger left temporal cortex activation than experienced players*".

The differences between experienced and inexperienced players in motor cortex activation were less consistent. According to Wolf et al. [69] experienced players should show a higher motor cortex activation than inexperienced players, however the results of this study were not completely in line with that. Although this phenomena was observable for the first channel, it was not for the other two channels (see Figure 5.6). In fact, the third channel showed the complete opposite result. Therefore the results of this study do not support the seventh hypothesis, which stated that "*Experienced players a higher motor cortex activation than inexperienced players*".

Although for the anxiety category the results were mostly in line with was expected from literature, the results regarding scoring and missing did not. For example, for experienced players the left temporal cortex was more activated when scoring a penalty, for most channels (see Figure 5.13). As explained before, an increase in left temporal cortex activation was expected to be related to neglecting automated skills and therefore to performing worse (i.e. missing penalties). For inexperienced players no consistent result were found, as for two channels the activation was similar when scoring and missing and the other two channels showed contradicting results (see Figure 5.13). Interestingly, for channel 14 the result was significant. This channel showed that for inexperienced players the left temporal cortex was significantly more activated when scoring a penalty. These results, however, do not (fully) support the thirteenth and fourteenth hypothesis (H13 and H14), which stated that "*Experienced player show a higher left temporal cortex activation when missing a penalty*" and "*Inexperienced players show lower left temporal cortex activation when missing a penalty*", respectively.

Similar contradicting results were obtained regarding the total PFC activation. For most channels the PFC was more activated when scoring, which is opposite of what was expected (see Figure 5.14). As explained before, it was expected that an increase in PFC activation would be a distracting factor and therefore result in a decrease in performance. However, the opposite was observable. This contradicts the second hypothesis (H2), which stated that "*The PFC is more activated when missing a penalty*".

For PFC asymmetry, however, the results were in line with what was hypothesised. For almost all channel-pairs the right PFC was more activated, as compared to the left PFC, when missing a penalty (see Figure 5.15). For the channel-pairs Ch7-Ch10 and Ch5-Ch10 the result was also significant (see Table 5.7). This is again in line with the theories of Hatfield and Kerick, Meyer et al. and Silveira et al. [21, 91, 92]. These results support the third hypothesis (H3), which stated that "*The PFC activation is more symmetrical (stronger right PFC activation) when missing a penalty*".

To summarise, most results found regarding the difference between anxious and not anxious players were in line with the related literature. An increase in task-relevant brain areas (the motor cortex) was related to being less anxious and an increase in task-irrelevant areas (total PFC activation) was related to being more anxious. For the left temporal cortex an increase in activation caused a distraction for experienced players, which is reflected in being more anxious, and inexperienced players showed less anxiety when the left temporal cortex was more activated. No similar results were, however, found regarding scoring and missing penalties. For the left temporal cortex and the total PFC activation (task-irrelevant), opposing results were found. The PFC was namely more activated when scoring and the left temporal cortex was more activated for experienced that scored a penalty. However, this was not the case for the motor cortex and PFC asymmetry. An increase in motor cortex activation (task-relevant) was namely related to scoring and a higher right compared to left PFC activation was related to missing a penalty. These results support the following hypotheses: H1, H3, H4, H5, H6, H10, H11 and H12. It has to be noted that not all results were significant. When only considering the significant results, the following hypotheses are supported: H1, H3, H4 and H5.

6.3 Performing under Pressure

Similar to the results of Lee and Grafton [98], and increase in dorsolateral prefrontal cortex (DLPFC) and motor cortex connectivity was observable when performing during the highest pressure round (see Table 5.8). Both the average z-value and number of connected channels were higher when scoring as compared to missing during round 3. For both variables (number of connections and the average z-value) the results could, however, not be considered significant. Although, the number of connected channels was close to being significant, with a p-value of $p = 0.05136$.

Similarly, the DLPFC-motor cortex connectivity was larger when scoring a penalty whilst being anxious. Both the average z-value and the number of connected channels increased when scoring a penalty (see Table 5.8). However, the differences between scoring and missing are smaller for this condition.

It has to be mentioned that a drawback of calculating correlation-based connectivity, as applied in this experiment, is that it can be sensitive to noise [118, 133]. Although most motion-related artefacts were removed during the pre-processing steps, such artefacts could have had an influence on these connectivity results. Motion artefacts are namely observable in all channels in a similar way (peaks at the same timestamp in all channels), which could falsely have been interpreted as a high connection between the channels.

Nonetheless, these results show that an increase in DLPFC-motor cortex connectivity is related to performing under pressure. Although the results were not significant, it can still be argued that the connectivity between the DLPFC and the motor cortex plays a role in performing under pressure. Especially because similar results were obtained during pilot test A (see Appendix A). This would also indicate that a decrease in connectivity could lead to choking under pressure. Although the results cannot be considered significant, they do support the eighth and ninth hypothesis (H8 and H9), which stated that: "*A stronger average average connectivity between the motor cortex and the DLPFC (z-values) is related to scoring a penalty when being anxious*" and "*More connected channels between the motor cortex and the DLPFC (number of connections) is related to scoring a penalty when being anxious*", respectively.

6.4 Contrasting Results within Brain Regions

It is interesting to see that for most brain region there was no overall increase or decrease of activation over all channels of that region. For example, when comparing anxious and not anxious players regarding their total PFC activation, it can be seen that around half of the channel-pairs showed increased activation and the other half showed a decrease in activation (see Appendix C.2). The difference between the highest and lowest activated channel for anxious players was higher than for players that were not anxious. This means that there was a greater difference in activation between channels of the PFC when being anxious as compared to not being anxious. In other words, there was a higher contrast between the activation of each channel. Similar observations were made for the other brain regions.

This is similar to the findings of Kuriyama et al. [8] (see Section 3.4 and in particular Figure 3.12). Their results showed that expert goalkeepers showed a higher contrast in PFC activation than novice goalkeepers. Where novice goalkeepers had a similar activation all over the PFC, experts showed more contrasting activation, with regions that were more activated and other regions that were less activated. Based on these results Kuriyama et al. concluded that experts showed an increased PFC activation.

The results of Kuriyama et al., are a possible explanation of the contrasting results found within each brain area in this study. The increase in brain activation may namely not be observable in all channels of that brain area, but only in a few.

6.5 Hard to Classify the Data

The classification results of the SVM (Support Vector Machine) showed that it was hard to successfully classify the data for all categories. Although all classification results were above the chance level of 50%, no remarkably good classification results were found (see Table 5.9). The best result on the test-set was 64.1%, which was achieved by classifying between anxiety and no anxiety using all channels related to the total prefrontal cortex (PFC) activation.

This shows that the data is not nicely spread, making it difficult to classify. The scatter plots of Figure 6.1 demonstrate this. In these plots the data is plotted for the first and second principal component for the three different categories (experienced vs inexperienced, anxiety vs no anxiety and scoring vs missing). For each category the brain region with the best classification result for that category was used. This means that for the experience category, the motor cortex data was used. For the anxiety category, the total PFC data was used and for the scoring category, the PFC asymmetry data was used. As can be seen in these plots, for all categories most datapoints are clustered together, making it difficult to successfully classify the data.

Other potential reason for the low classification results was the relatively small size of the train- and test-set. There were a total of 330 trails, which meant that the train-set contained 264 trails and the test-set 66 trails. When using a larger dataset the classifier can be trained and tested on more trails, which should increase its performance. Another option would be to use a moving window approach, as it has been shown in previous fNIRS studies that classifier results can be improved by focusing a specific window [134]. Using this approach, the best window (chunk of data) for classification can be selected. Furthermore, a more advanced classifier could potentially achieve a better performance. In this study an SVM was used, as the aim was to simply get an idea of how easy or hard it was to classify the data and not to achieve the best classification performance possible. Furthermore, an SVM is rather simple to set-up. Other classifiers may perform better on the current dataset.

Overall, the classification results show that although there were some significant results found, it is still hard for an SVM to successfully classify the data.

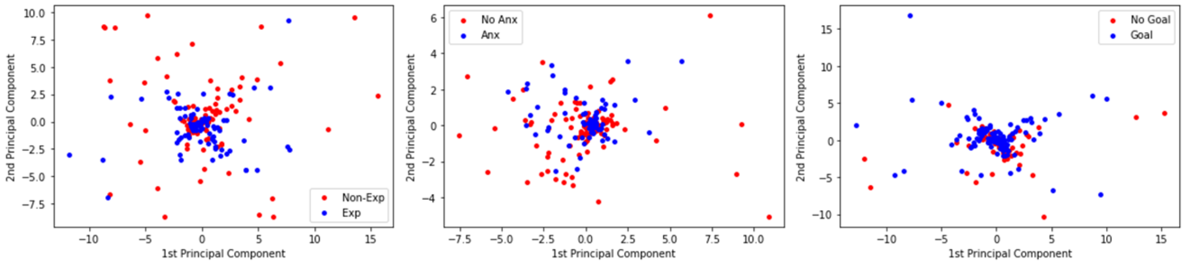

Figure 6.1: Scatter plots to show the spread of the data. From left to right the plots represent: experienced vs inexperienced players using motor cortex data, anxiety vs no anxiety using total PFC data and scoring vs missing using the PFC asymmetry data. For each plot the x-axis represents the first and the y-axis the second principal component.

6.6 Limitations and Suggestions for Improvements

The largest limitation of this research is the fact that the majority of the data was unusable due to the presence of motion artefacts. Because of this, around 60% of the data was removed during the pre-processing steps. Preferably less motion artefacts are present in the data, in order to remain more data for the analysis. A way to solve this would be to increase the waiting period before each penalty. In the current experiment, participants had to wait for 5 seconds before taking the penalty. This waiting period could be increased to 10 seconds. One could, for example, pick a 5-second segment out of these 10 seconds, which shows the cleanest data. This would decrease the probability of motion artefacts in the signal. Furthermore, participants could have been better instructed about minimising their movement during this waiting period. During the experiments it became clear that the participants were very eager to take the penalty and therefore were not standing perfectly still during the waiting time. This shows how motivated the participants were to do the task, however it also meant that more motion artefacts were present in the signals.

During this study some significant results were found. However, it has to be noted that no multiple testing correction was done to check if these statistical results contained any false positives. A multiple testing correction is a method to correct for accidental statistical results when doing a large quantity of statistical tests. It is namely evident that the chances of accidental significant results (results which are falsely considered as being significant), increases when doing a large amount of tests. When using a False

Brain Area	Channel	Check	P-Value	Rank	(I/m)Q
PFC Asymmetry	Ch7-Ch10	A higher left compared to right PFC activation is related to scoring	0.00050	1	0.00062
Total PFC	Ch8-Ch9	Anxious players show higher activation	0.00105	2	0.00123
Left Temp. Cortex	Ch14	Inexperienced players show increased activation when scoring	0.00132	3	0.00185
Total PFC	Ch8-Ch10	Anxious players show higher activation	0.00627	4	0.00247
PFC Asymmetry	Ch6-Ch12	Anxious players show higher right compared to left PFC activation	0.00921	5	0.00309
PFC Asymmetry	Ch8-Ch12	Anxious players show higher right compared to left PFC activation	0.01639	6	0.00370
Motor Cortex	Ch1	Anxious players show lower activation	0.01700	7	0.00432
PFC Asymmetry	Ch5-Ch10	A higher left compared to right PFC activation is related to scoring	0.03885	8	0.00494
Left Temp. Cortex	Ch15	Anxious experienced players show higher activation	0.04260	9	0.00556
Total PFC	Ch5-Ch9	Anxious players show higher activation	0.04335	10	0.00617
Total PFC	Ch7-Ch9	Anxious players show higher activation	0.04824	11	0.00679

Table 6.1: Statistical results of the permutation test after FDR correction. All significant results before correction are included. The blue rows represent the significant results after FDR-correction. A results was considered significant if the p-value was lower than $(I/m)Q$, where I represents the rank; m the total amount of statistical tests ($m = 81$) and Q the significance threshold ($Q = 0.05$).

Discovery Rate (FDR) test as correction procedure, with $Q = 0.05$ and $m = 81$, 3 out of the 11 significant results remain (where Q indicates the significance threshold and m the number of statistical tests). In Table 6.1 the statistical results after FDR correction are shown. In this table only the tests with a p-value below 0.05 are included, however all 81 tests were used for the FDR correction procedure. The FDR correction is more often applied to channel-wise fNIRS analysis, similar to this study [135]. These FDR-corrected results imply that most significant results that were found in this study, were accidental. Meaning that most significant results were incorrectly marked as being significant. The only significant results that remain after the correction are: the left PFC is more activated than the right PFC when scoring a penalty, anxious players show a higher total PFC activation and inexperienced players show an increased left temporal cortex activation when scoring a penalty. These results are, however, based on a single channel or channel-pair. Although most results are not significant after FDR-correction, these results are still in line with what was found in the literature. Therefore, although no direct conclusions can be drawn for the results of this study alone, the results can still be seen as a support of the theories that were found in the literature.

Within the current study, scoring a penalty was seen as performing and missing a penalty as failing to perform. However, this may not be the best measurement to use for this comparison. Scoring a penalty does namely not necessarily indicate that the penalty was taken well. For example, the goalkeeper can make a mistake, meaning a badly taken penalty can still be a goal. Also missing a penalty does not necessarily mean that a penalty was taken badly, as a goalkeeper can still save a penalty by guessing the right direction. It would therefore be recommended to, instead, look at the quality of the penalty. This can be done by, for example, looking at the shot-placement and shot-power.

Although pressure was successfully induced during this experiment, the levels of pressure are not the same as during a match-like situation. The levels of pressure during an important (professional) football match were not met and therefore it is uncertain if the pressure was high enough to induce choking. A way to increase this level of pressure during an experiment, could be to have a spectating audience. It is well known that having other people spectating when trying to execute a task, increases the level of pressure. Although there were sometimes a few other people around during certain experiments, the true presence of an audience was lacking in the current study.

As the experiment was held outside, there were some conditions that were not constant for each experiment (see Section 4.4). These variable conditions could have had an influence on the results. This potential influence has not been looked into during this study. Most of these conditions were related to the weather. Using an indoor football pitch would solve this.

At last, there were a few participants that indicated that wearing the fNIRS cap and the presence of the GoPro camera's were distracting factors. This was however only the case for a few participants. Still it could have had an influence on their performance. In the current study the this potential influence was not looking into.

6.7 Directions for Future Research

Besides the suggested improvements named in the previous section (see Section 6.7), there are other interesting directions for future research into this subject.

For example, it would be interesting to include professional football players and to see if there are differences between professional players and amateur players (the experienced players participating in this study). It can be expected that professional players show even more efficient neural behaviour.

In the current study multiple methods were used in order to induce pressure and therefore it is unclear what the effects were of each method individually. Future research could be dedicated to looking into the effect of each method on the brain activity of participants. This way more information can be gained about what causes people to feel pressure. The current study was more focused on what brain activity was related to experiencing pressure.

Furthermore, future research could be done related whether performing under pressure is trainable using brain data. It would be interesting to know if receiving feedback about your brain activity could help you train to perform under pressure. If it is possible to train your brain in such a way, it could be very helpful for professional sport players or other professions where a physical performance under pressure is needed (such as surgeons). Moreover, it would be interesting to see whether pressure on different kinds of tasks, instead of a physical task (such as doing an exam - mental task), would also be in line with the neural efficiency theory. Other areas of the brain would be considered task-relevant or task-irrelevant during a mental task.

At last, the interaction between goalkeeper and player was not looked into extensively during this study. There certainly was an interaction between player and goalkeeper and this interaction became more prominent during the high pressure condition (player was looking more at the goalkeeper). It would be interesting to research if this interaction is also observable within the brain activity of the goalkeeper and the player. A more confident goalkeeper could, namely, make the player nervous and it would be interesting to see if this is reflected in the brain activity of player and goalkeeper as well.

6.8 Contributions

Among other things, one of the major contributions of this study is that it shows that it is possible to successfully conduct an "in the wild" fNIRS experiment. Only one study was found in literature where fNIRS was for such an experiment [9]. Similar to this study of Carius et al., the current study shows that it is possible to obtain reliable fNIRS results during an "in the wild" experiment, involving major movements. By implementing the suggested adaptations to the experiment, more reliable data can be obtained, which would improve the quality of the analysis even more.

Chapter 7

Conclusion

Within the present study, an "in the wild" penalty kick study was set-up in which pressure was successfully induced, in order to answer the following main research question: "*What brain activity is associated with choking under pressure in a penalty kick situation?*". This main research question was divided into five sub-research questions. These sub-research questions will be answered one by one.

What is the difference in brain activity between performing (scoring) and not performing (missing) when taking a penalty kick?
In accordance to the neural efficiency theory, the task-relevant areas of the brain were more activated when performing. The motor cortex was, namely, more activated when scoring a penalty. Furthermore, activating the task-irrelevant prefrontal cortex (PFC) was related to missing. This PFC activation showed itself in a higher right as compared to left PFC activation. The activation of the PFC can be seen as a distraction. This distraction is potentially caused by the long-term thinking ability of the PFC, as players might think about the consequences of scoring or missing the penalty. The results regarding the motor cortex were not found to be significant, whereas the results regarding the symmetrical PFC activation were significant.

What brain activity is associated with performing under pressure during a penalty kick situation?
The connectivity between the motor cortex and the dorsolateral prefrontal cortex (DLPFC) was shown to be related to scoring when being under pressure. As these results were not significant, it only gives an indication that this connectivity is related to performing under pressure.

What is the general difference in brain activity between expert and novice football players when taking a penalty kick?
More experienced football players showed a lower left temporal cortex activation than inexperienced football players. Again, these results were not significant. It therefore only is an indication. No conclusive remarks could be made, although this result was in line with numerous previous studies.

What brain activity is associated with expert football players that experience (performance) anxiety when taking a penalty kick?
Experienced players showed a higher left temporal cortex activation when being anxious.

As the left temporal cortex is related to self-instruction and self-reflection, this increased left temporal cortex activation indicates that experienced players ”overthink” the situation and neglect their automated skills. However, this results was not found to be significant and therefore only gives an indication.

What brain activity is associated with novice football players that experience (performance) anxiety when taking a penalty kick?
Unlike experienced players, inexperienced showed lower left temporal activation when being anxious. An explanation for this phenomena is that self-instruction and self-reflection are essential in the early stages of learning a motor skill. As inexperienced players still need to learn the skill, a higher left temporal cortex activation would be beneficial for them. When being anxious they potentially do not instruct themselves enough. Again, this result was not significant and therefore only gives an indication.

The total PFC activation was also related to players who experienced (performance) anxiety. A higher overall PFC activation was, namely, related to anxious players. Similarly, an increased right, as compared to left PFC activation was shown to be related to anxious players. These results apply to both experienced and inexperienced players. Both these results were significant.

Acknowledgements

I would like to thank the football clubs vv Drienerlo and vv Den Ham for their help and support during the actual experiment and a pilot experiment, respectively. In particular I would like to thank the goalkeeper of the experiments: Silvie van de Boogaard, Vincent Delke, Allyne Groen, Patrick van Oerle and Harry Vaassen, as they were so kind to reserve a lot of their time for the experiments. Vv Drienerlo was also very kind to let me do some experiments during their training. I would also like to thank Job van Regteren, Nicole Rohring (of the UT Sports Centre) and the BMS Lab for all their help regarding arranging everything around the experiment. Furthermore, Artinis and in particular Liucija Svinkunaite were also very helpful regarding the fNIRS equipment and Bluetooth dongle. Also the NOC*NSF (the Dutch overarching sports organisation), and in particular Sandra van Essen, were of much help with setting-up the experiment design. And at last I would like to thank my supervisors Mannes Poel and Natty Thammasan for all their advise, support and trust. I can imagine other supervisors would be more hold back about such an "in the wild" study involving fNIRS measurements and therefore I am very thankful for their confidence.

Appendix A

Pilot Tests

A.1 Pilot Test One

The aim of the first pilot test was to get some first insights into the brain activation whilst being under pressure. Furthermore, within this first pilot test the methods for pressure induction and the data analysis pipeline could be designed and evaluated. During this first experiment a game of darts was played instead of kicking penalties, as the experiment had to be done at home due to the Covid-19 restrictions. Inside the home there was not enough space for a penalty kick task. Although dart throwing and penalty kicking are totally different skills, the effects of pressure on the brain can still be measured during a darts game. A total of six participants participated in the study (all male and right-handed) and half of the participants the brain activity was measured.

The experiment consisted of three rounds where the aim was to induce more pressure per round. In the first round the players played on there own and in the second round they played against each other. However, in the second round the players were not allowed to interact with each other. In the last round the winner would get a prize (Ben & Jerry's ice cream) and the players were allowed to distract and trash-talk each other. The State-Trait Anxiety Inventory (STAI) questionnaire [20] was used to measure the level of pressure. When looking at the STAI-scores it became clear that there was no increase in pressure between the second and the third round. Participants also indicated that they did not experience more stress or anxiety during the last round.

Furthermore, the Brite 24 of Artinis was used to measure changes in the oxygenation of the brain (fNIRS). A number of brain measurements were made: the total prefrontal cortex (PFC) activation, the asymmetry between left and right PFC activation, the motor cortex activation, the left temporal cortex activation and the connectivity between the dorsolateral prefrontal cortex (DLPFC) and the motor cortex. Unfortunately due to the noisiness of the O2Hb channels and the too strict filtering methods, almost no O2Hb data was available. This was an indication that less strict and more advanced methods were needed than the current method, based on the standard deviation of each channel. All channels with a standard deviation above 1.0 were removed, which let to a total of 44.1% of the data to be removed.

Still, some interesting results were gathered from this experiment. An increase in total PFC activation, an increase in left temporal cortex activation and a decrease in motor cortex activation were found to be related to a better performance. Also, a more asymmetrical PFC activity was related to successful throws. Furthermore, the PFC activation became more symmetrical in the last round (highest pressure condition). Most consistent results were found regarding the connectivity between DLPFC and the motor cortex. Namely, a higher connectivity was related to a better performance and this connectivity was most dominant during the highest pressure condition. This could be an indication that the participants were able to deal with the pressure, which could also be an explanation of the better results in the last round. One drawback of correlation-based connectivity, as applied in this experiment, is that it can be sensitive to noise [118, 133].

A.2 Pilot Test Two

For the second pilot test, new methods to induce pressure were set-up, these were tested and evaluated in this pilot experiment. During the experiment, four experienced football players took 9 penalties divided over three rounds. During the first round no goalkeeper was present and during the second round a goalkeeper was present but was not allowed to distract the players. During the last round the goalkeeper was allowed to distract and trash-talk the player. Furthermore, the goalkeeper was instructed to waste some time and call the player by his first name often. At last, the player had to indicate beforehand in what corner they were going to shoot the ball. The State-Trait Anxiety Inventory (STAI) [20] was used to measure the level of pressure.

The results of the STAI questionnaire and the comments of the players indicated that they did not experience an increase of pressure or anxiety during the last round. They indicated that because they had to pick a corner beforehand, the pressure was lower. There were namely fewer choices to make now, when kicking the penalty. Furthermore, as there was some confusion about the questionnaire and that the items of this questionnaire did not corresponds to what the players were experiencing. For example, one item was related to whether the player was "confused", which would be possible when being anxious in general, however less when competing in a sport.

Based on the insights gained in this experiment it was therefore decided to use a different questionnaire to measure pressure. One that is preferably more specifically related to anxiety in sport. Also, a different method to induce pressure would be needed. The aim of this new method should be to give the player a lot of choices to make in order to let them worry about there decision. Therefore, the players should not beforehand pick a corner. Furthermore, the goalkeeper could try to let the player worry by telling them he or she already knows in what corner they will shoot the ball. By giving the players more time to think and worry, the effect can also be achieved. Therefore, letting the players wait for a longer period of time could induce the pressure some more. The goalkeepers could therefore waste some more time.

Appendix B

Correlation Threshold Comparison

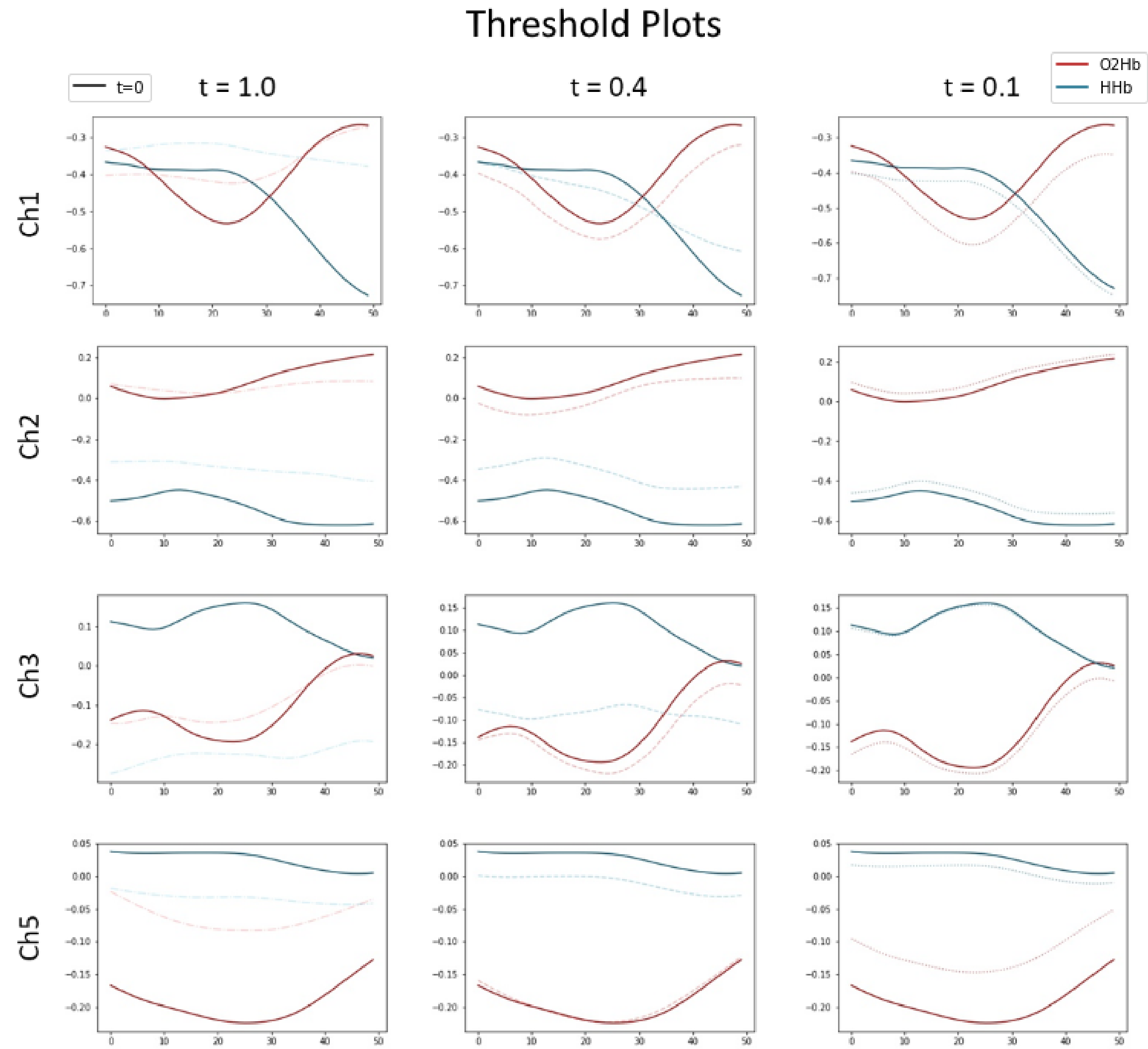

Figure B.1: Comparison between different correlation coefficient thresholds for the channels 1, 2, 3 and 5. In each plot the optimal threshold of t=0.0 (solid lines) is compared to other thresholds (t=1.0, t=0.4 and t=0.1), represented by the columns. All plots show average results over all trails. Red lines indicate O2Hb concentrations and the blue lines HHb concentrations.

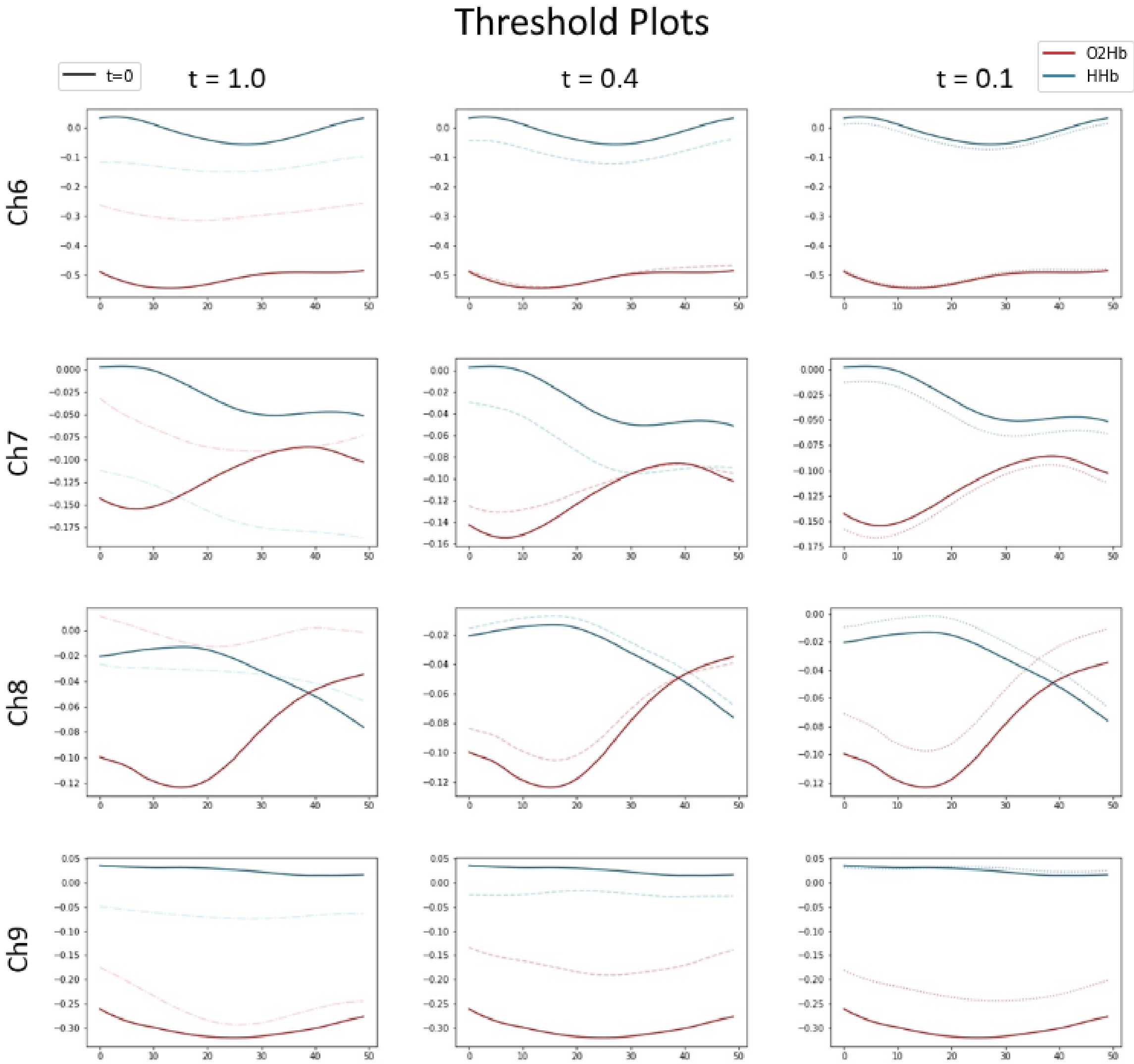

Figure B.2: Comparison between different correlation coefficient thresholds for the channels 6, 7, 8 and 9. In each plot the optimal threshold of t=0.0 (solid lines) is compared to other thresholds (t=1.0, t=0.4 and t=0.1), represented by the columns. All plots show average results over all trails. Red lines indicate O2Hb concentrations and the blue lines HHb concentrations.

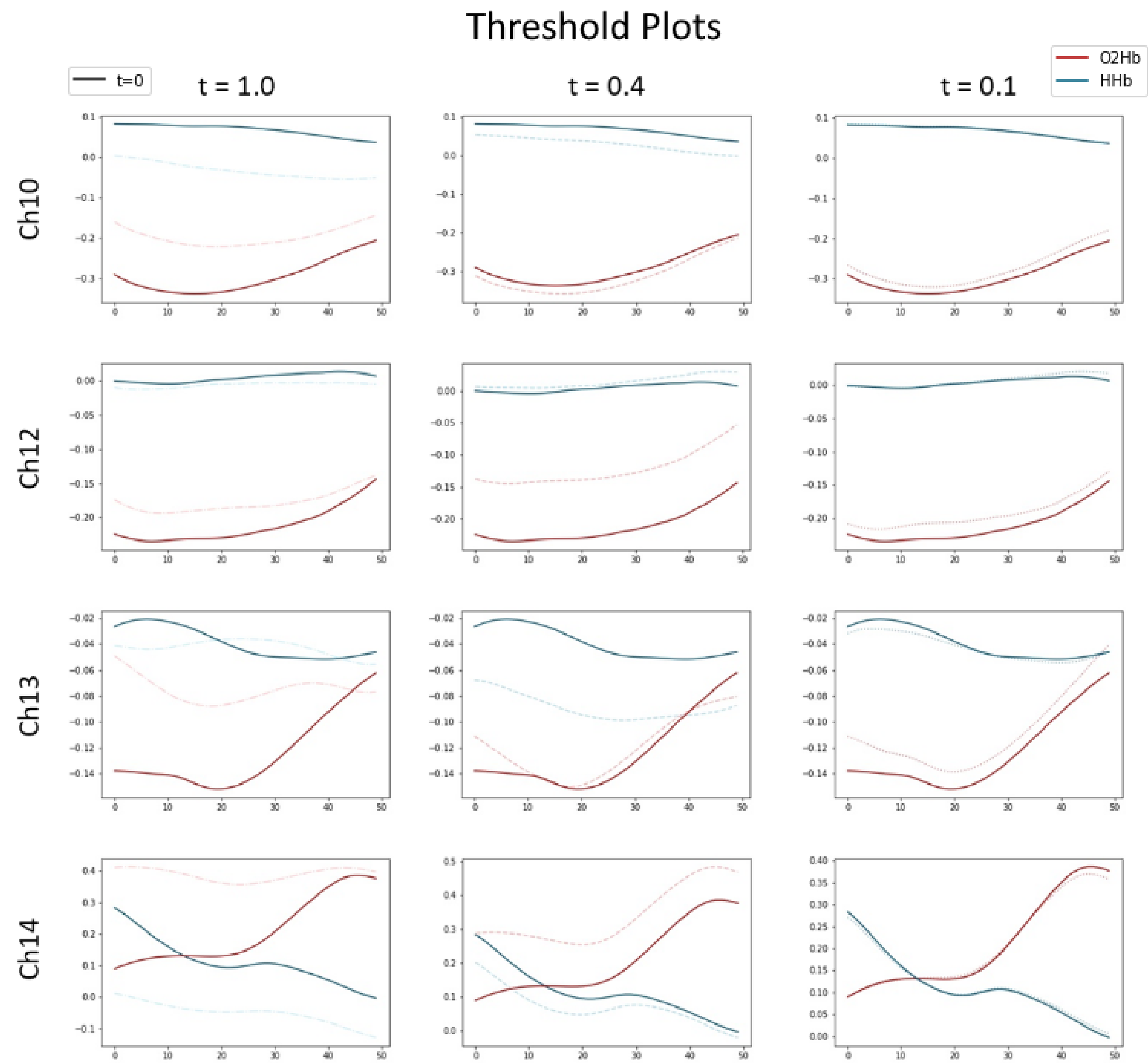

Figure B.3: Comparison between different correlation coefficient thresholds for the channels 10, 12, 13 and 14. In each plot the optimal threshold of t=0.0 (solid lines) is compared to other thresholds (t=1.0, t=0.4 and t=0.1), represented by the columns. All plots show average results over all trails. Red lines indicate O2Hb concentrations and the blue lines HHb concentrations.

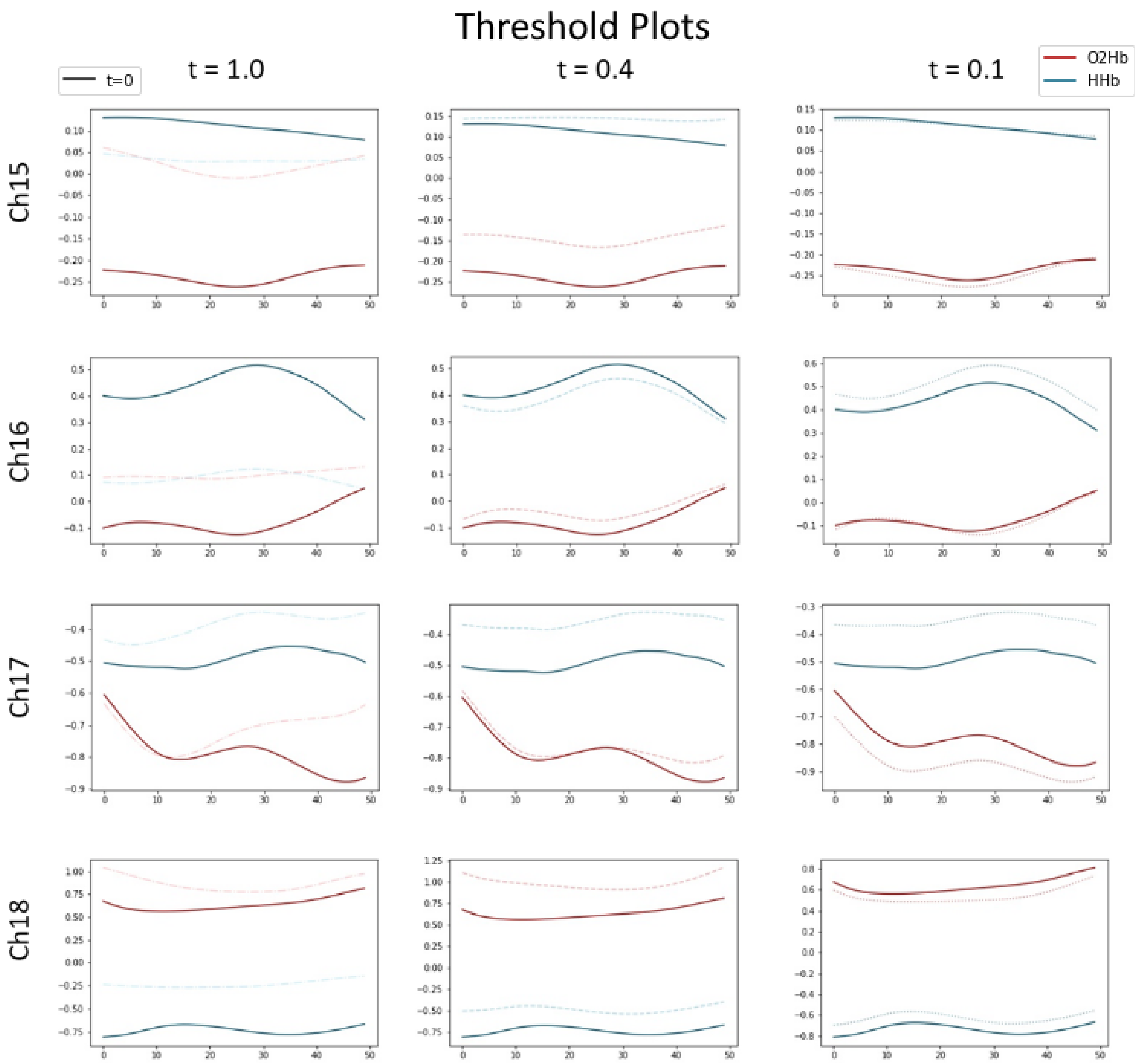

Figure B.4: Comparison between different correlation coefficient thresholds for the channels 15, 16, 17 and 18. In each plot the optimal threshold of t=0.0 (solid lines) is compared to other thresholds (t=1.0, t=0.4 and t=0.1), represented by the columns. All plots show average results over all trails. Red lines indicate O2Hb concentrations and the blue lines HHb concentrations.

Appendix C

Plots of Brain Activity Results

C.1 Exp vs Non-Exp

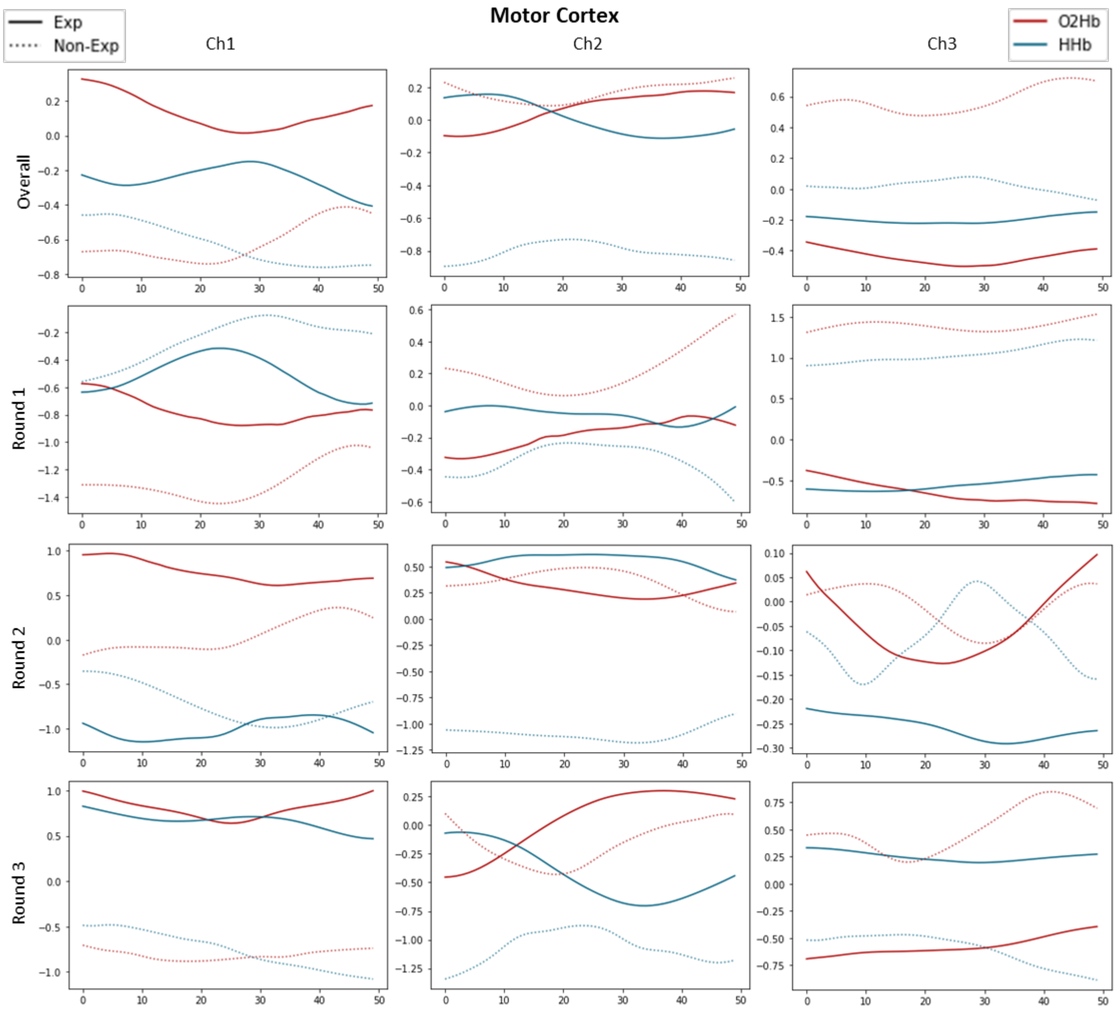

Figure C.1: Plots corresponding to the average motor cortex activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. From left to right the channels 1 to 3 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

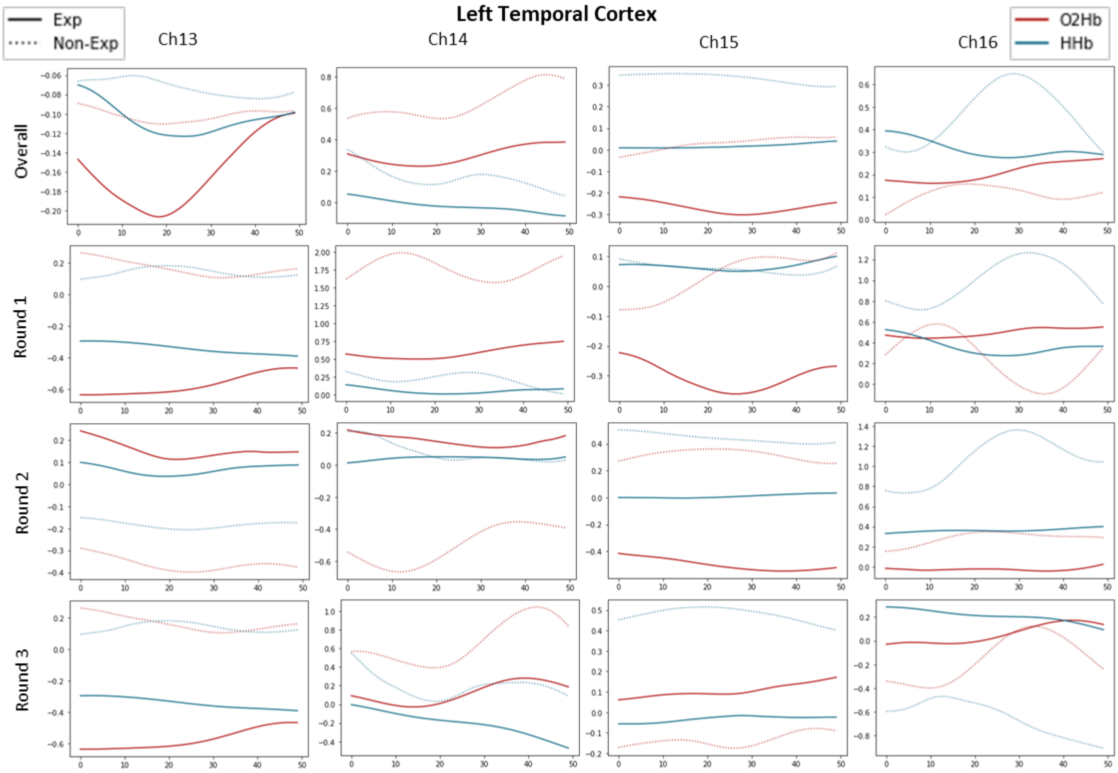

Figure C.2: Plots corresponding to the average left temporal cortex activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. From left to right the channels 13 to 16 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

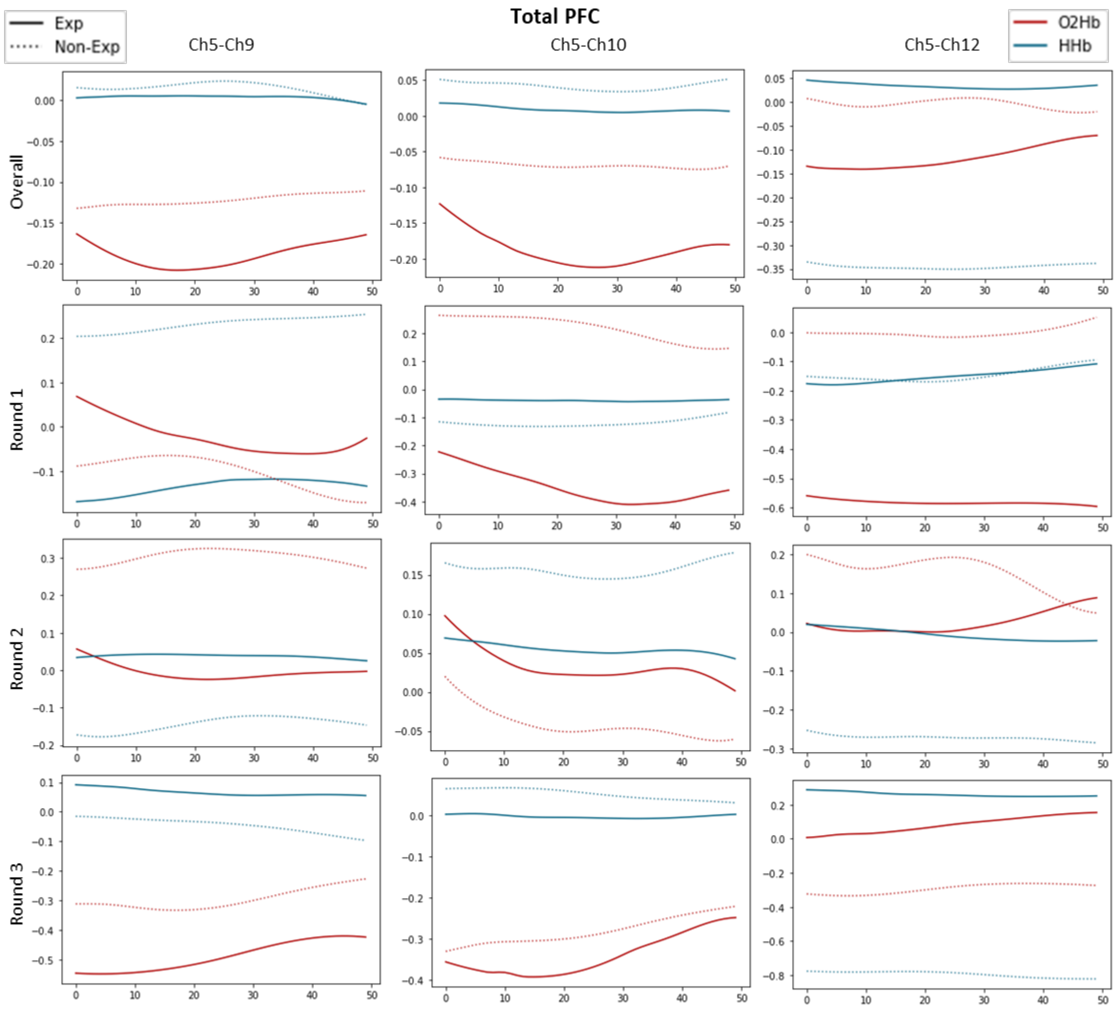

Figure C.3: Plots corresponding to the average total PFC activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. All channels-pairs with Ch5 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

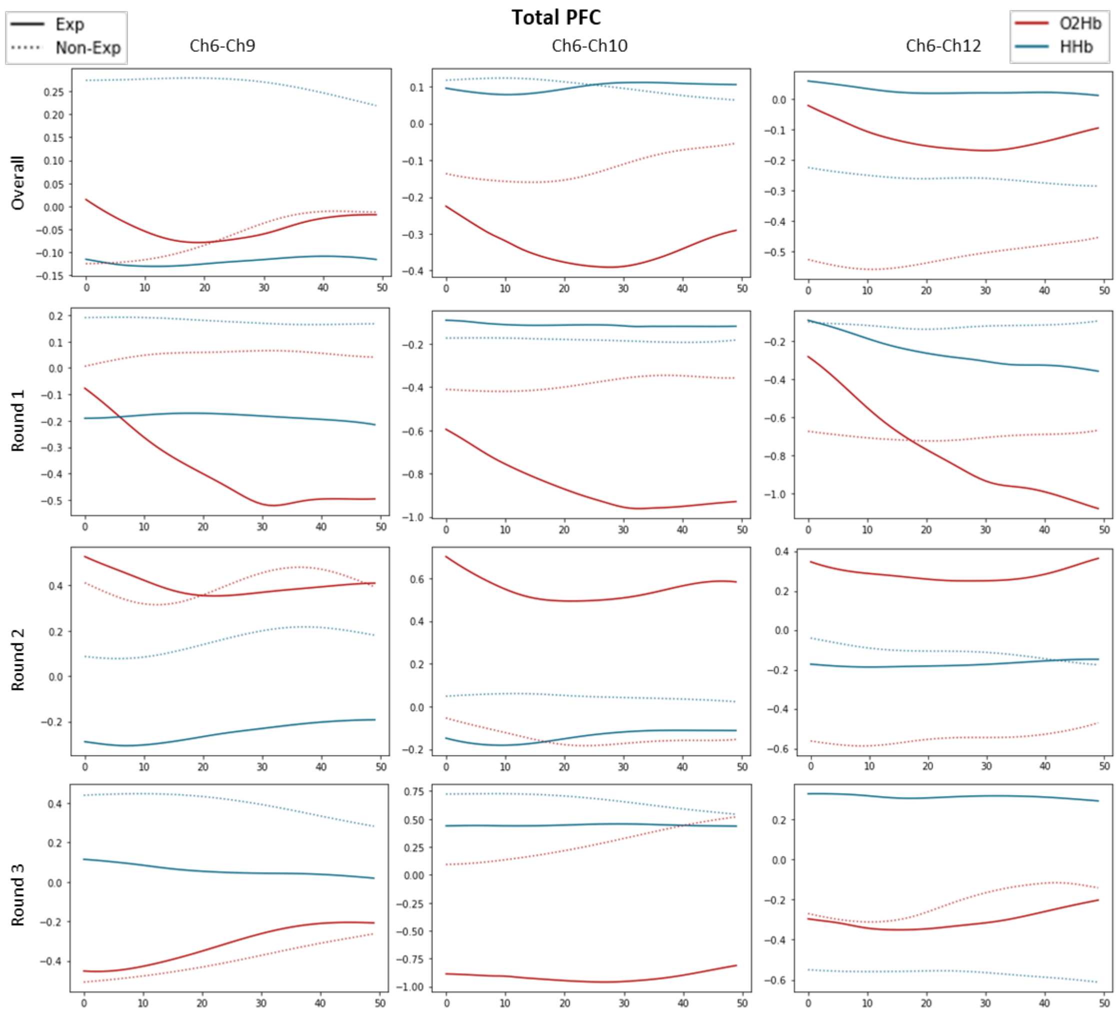

Figure C.4: Plots corresponding to the average total PFC activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. All channels-pairs with Ch6 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

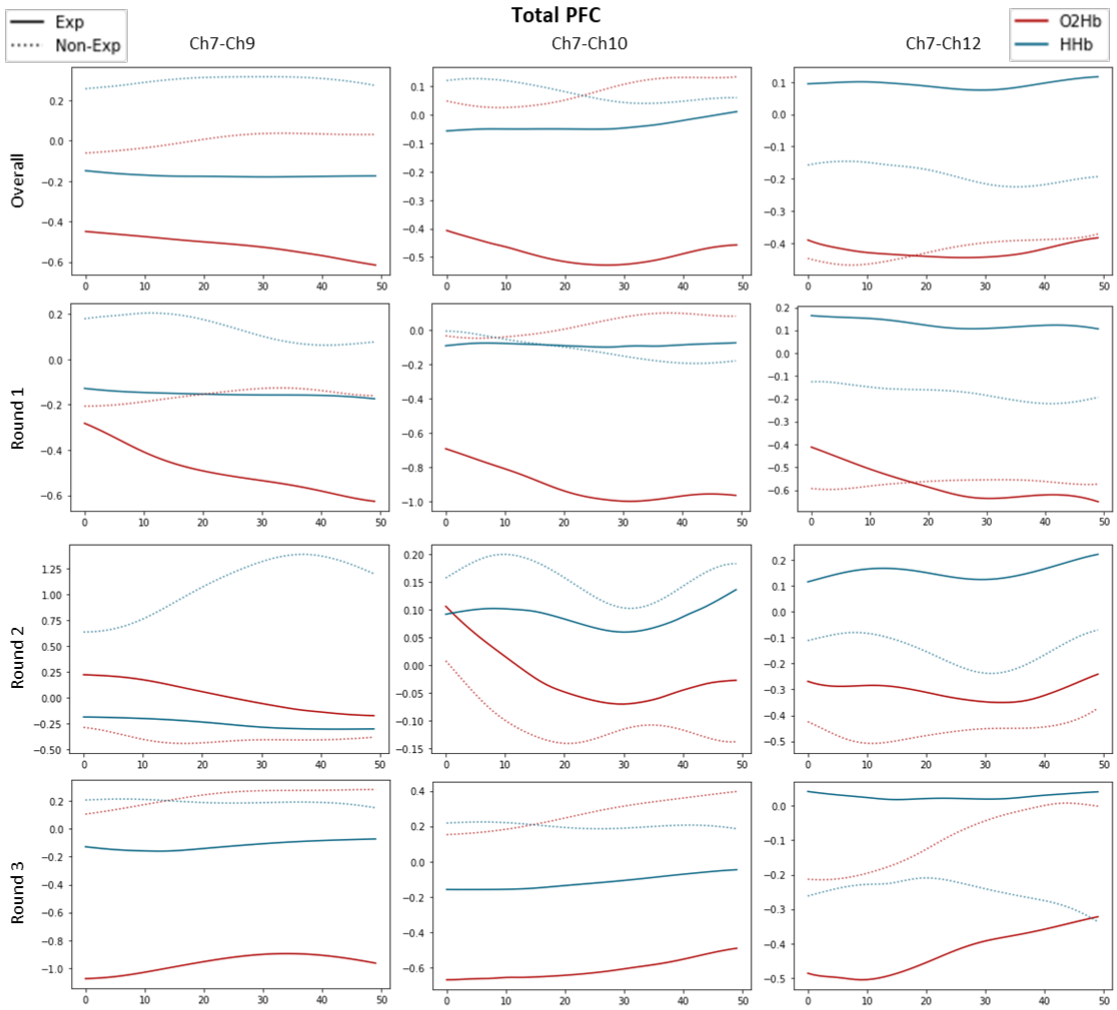

Figure C.5: Plots corresponding to the average total PFC activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. All channels-pairs with Ch7 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

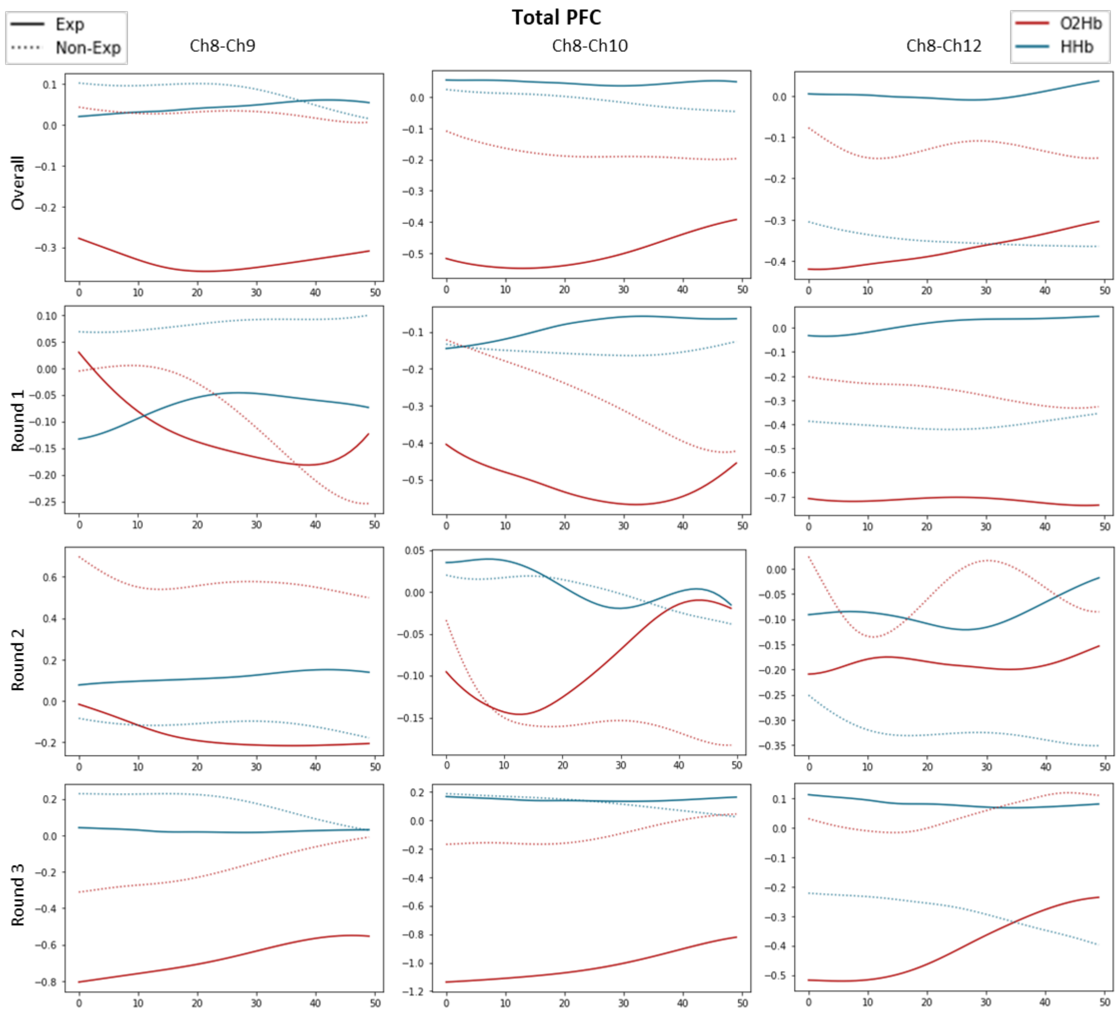

Figure C.6: Plots corresponding to the average total PFC activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. All channels-pairs with Ch8 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

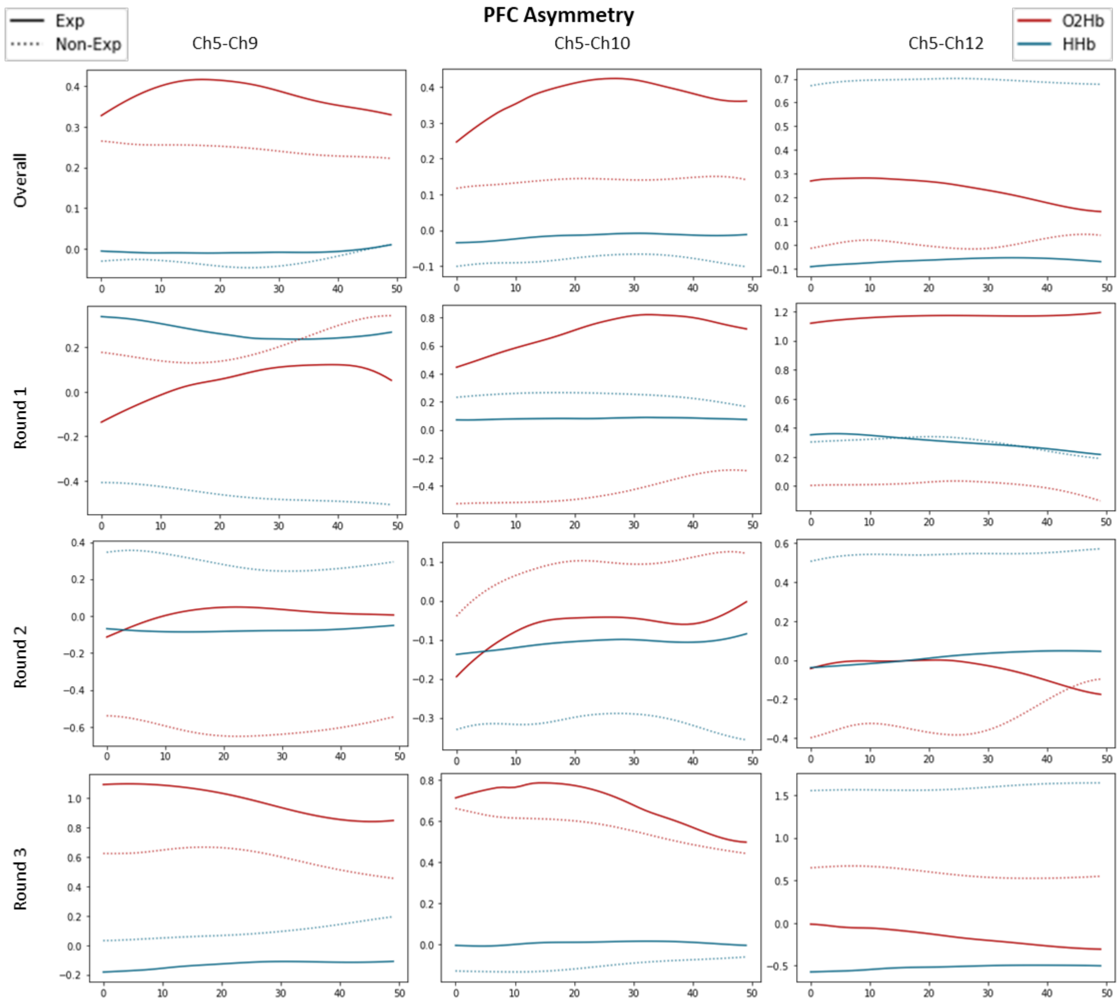

Figure C.7: Plots corresponding to the average PFC asymmetry activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. All channels-pairs with Ch5 (right PFC) are included. A positive asymmetry value indicates a higher right as compared to left PFC activation. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

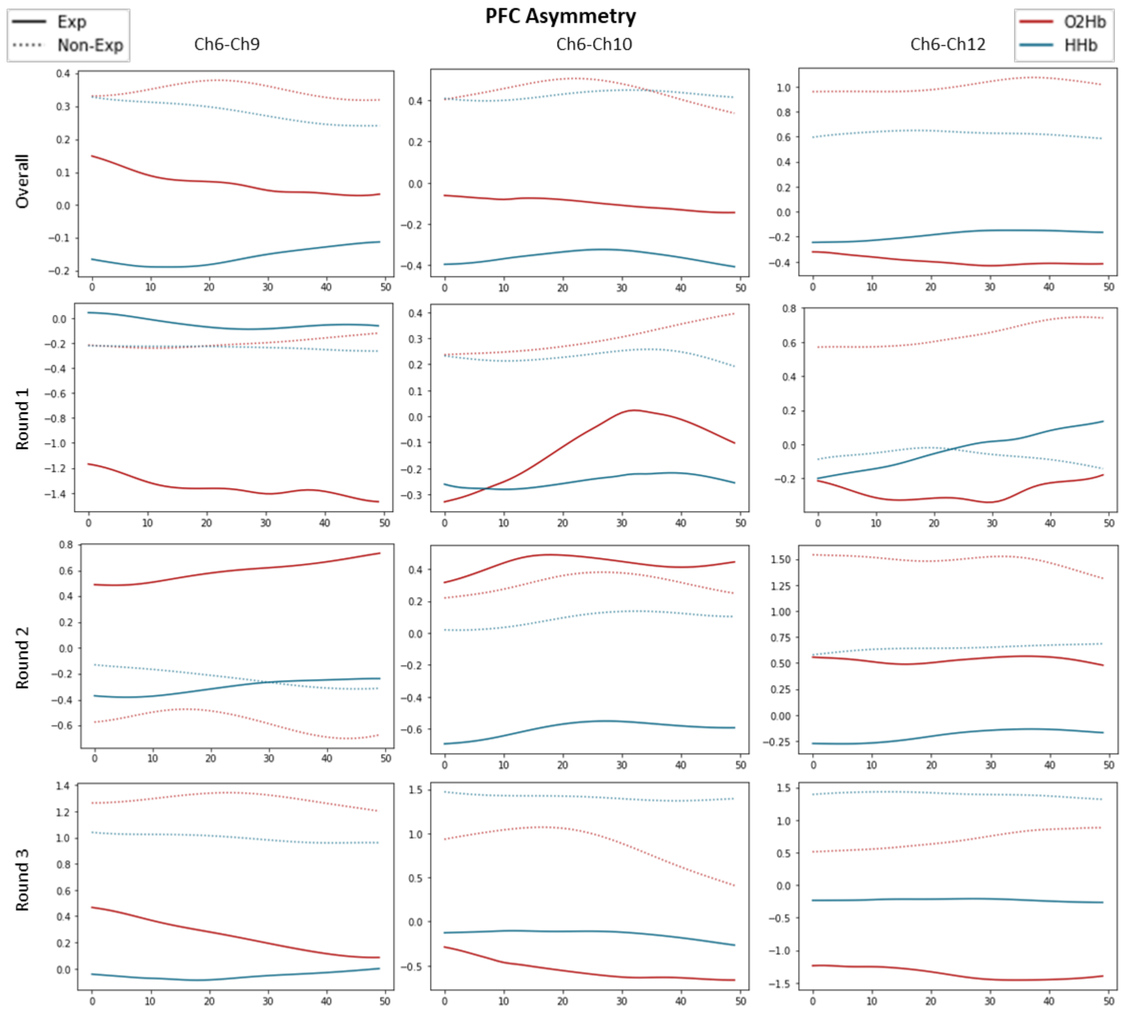

Figure C.8: Plots corresponding to the average PFC asymmetry activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. All channels-pairs with Ch6 (right PFC) are included. A positive asymmetry value indicates a higher right as compared to left PFC activation. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

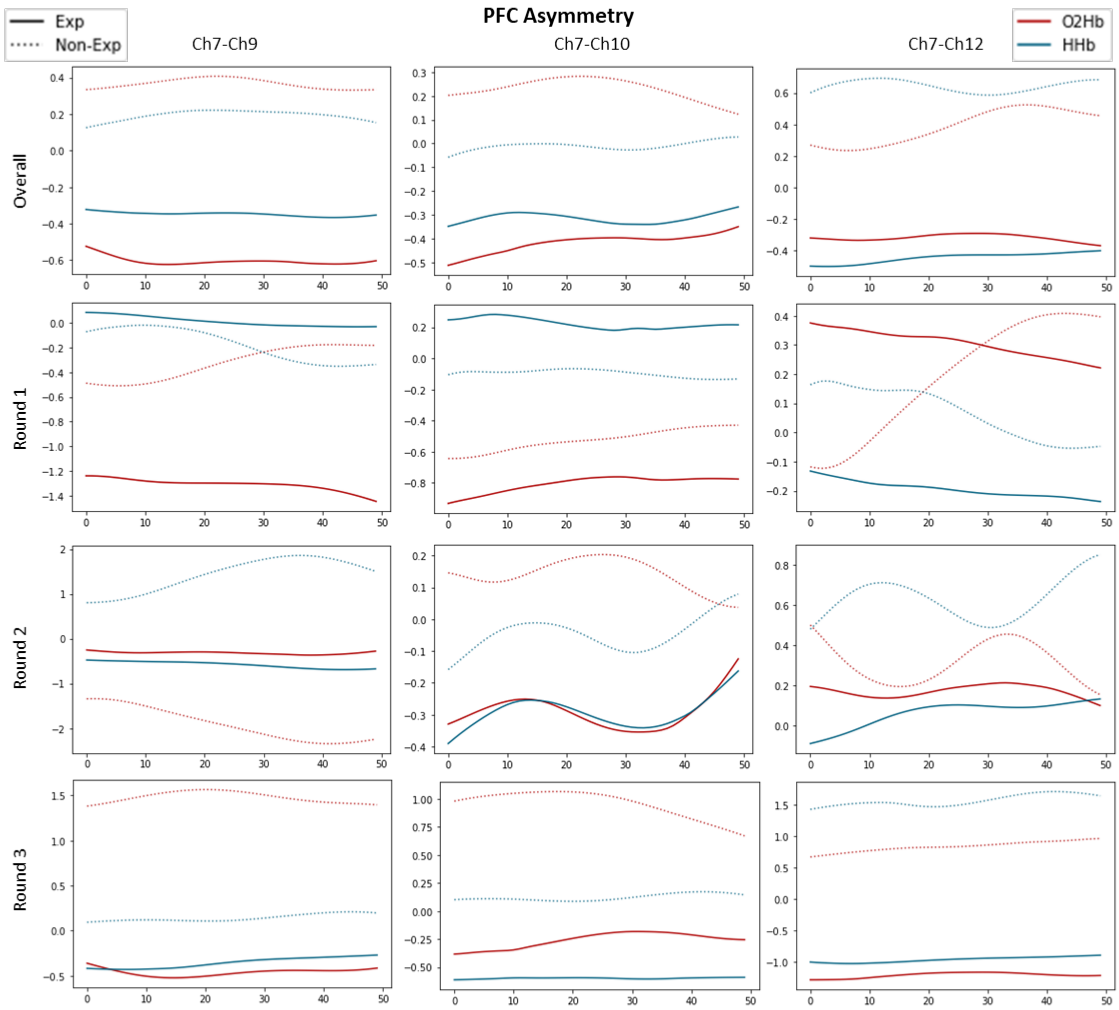

Figure C.9: Plots corresponding to the average PFC asymmetry activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. All channels-pairs with Ch7 (right PFC) are included. A positive asymmetry value indicates a higher right as compared to left PFC activation. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

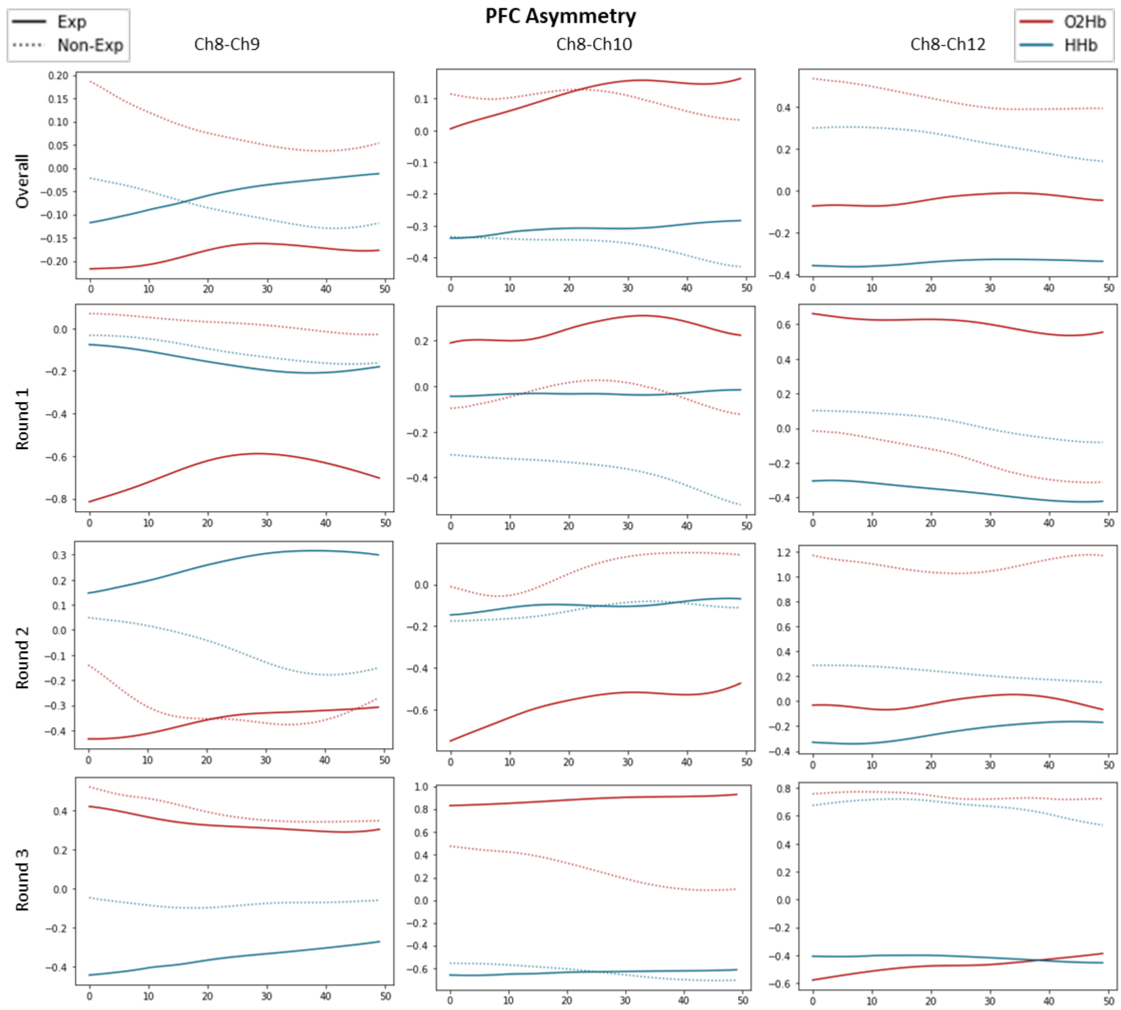

Figure C.10: Plots corresponding to the average PFC asymmetry activation for experienced and inexperienced players. The overall results (all rounds) and the results for each round individually are shown. All channels-pairs with Ch8 (right PFC) are included. A positive asymmetry value indicates a higher right as compared to left PFC activation. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Experienced players are represented by a solid line and inexperienced players by a dotted line.

C.2 Anxiety vs No Anxiety

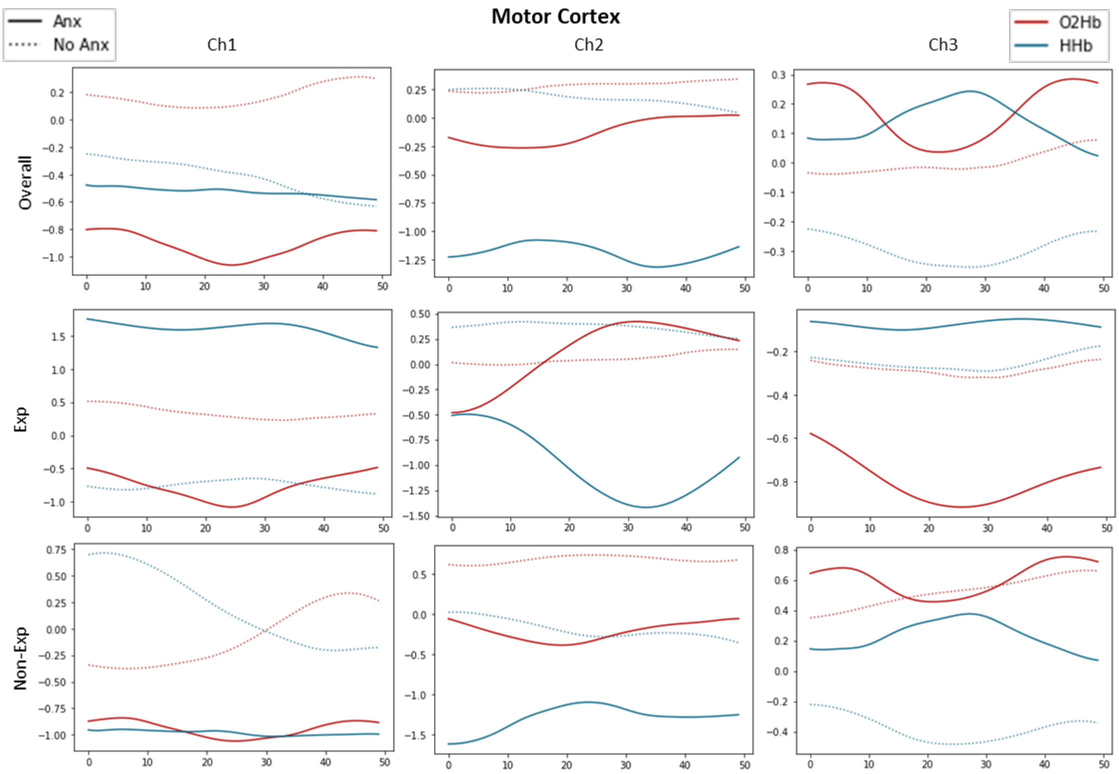

Figure C.11: Plots corresponding to the average motor cortex activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. From left to right the channels 1 to 3 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

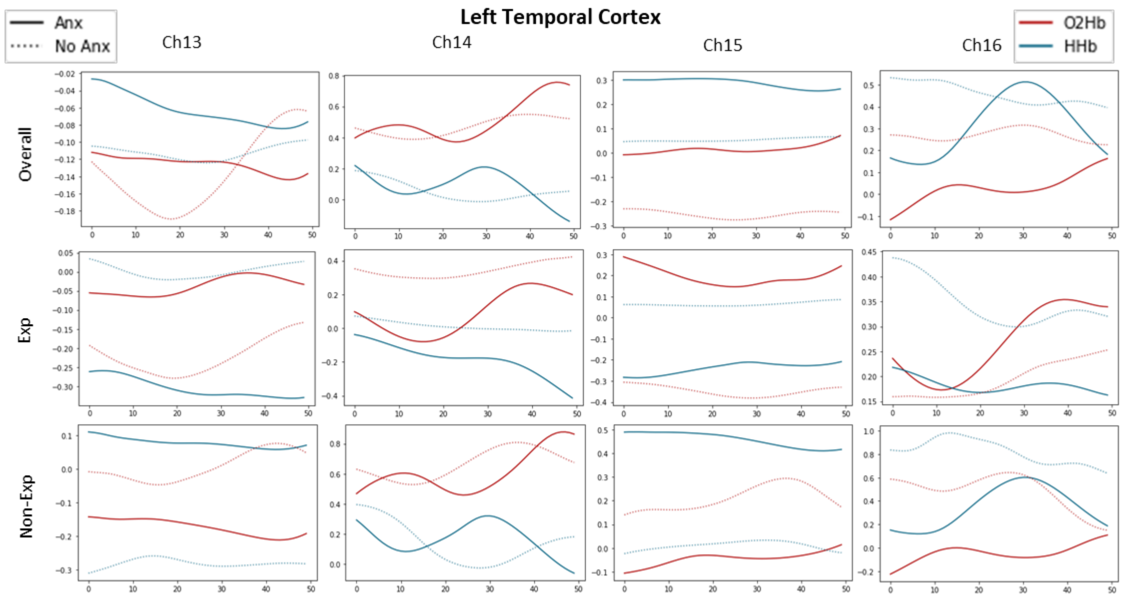

Figure C.12: Plots corresponding to the average left temporal cortex activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. From left to right the channels 13 to 16 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

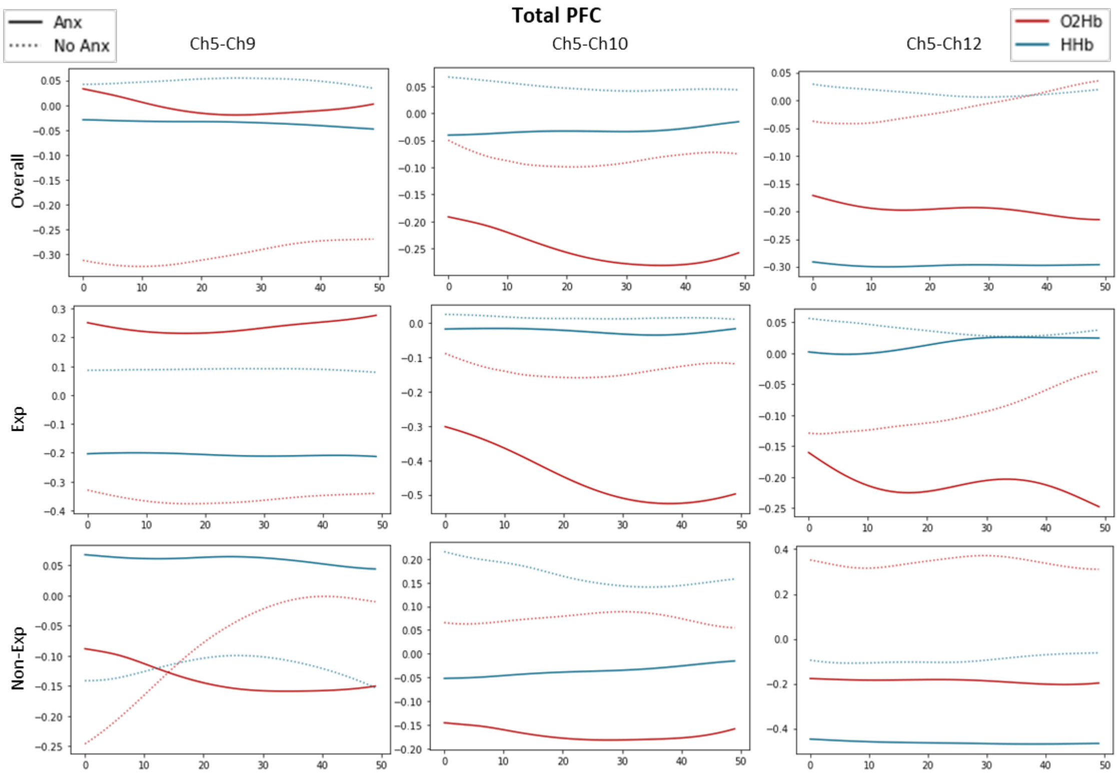

Figure C.13: Plots corresponding to the average total PFC activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. All channels-pairs with Ch5 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

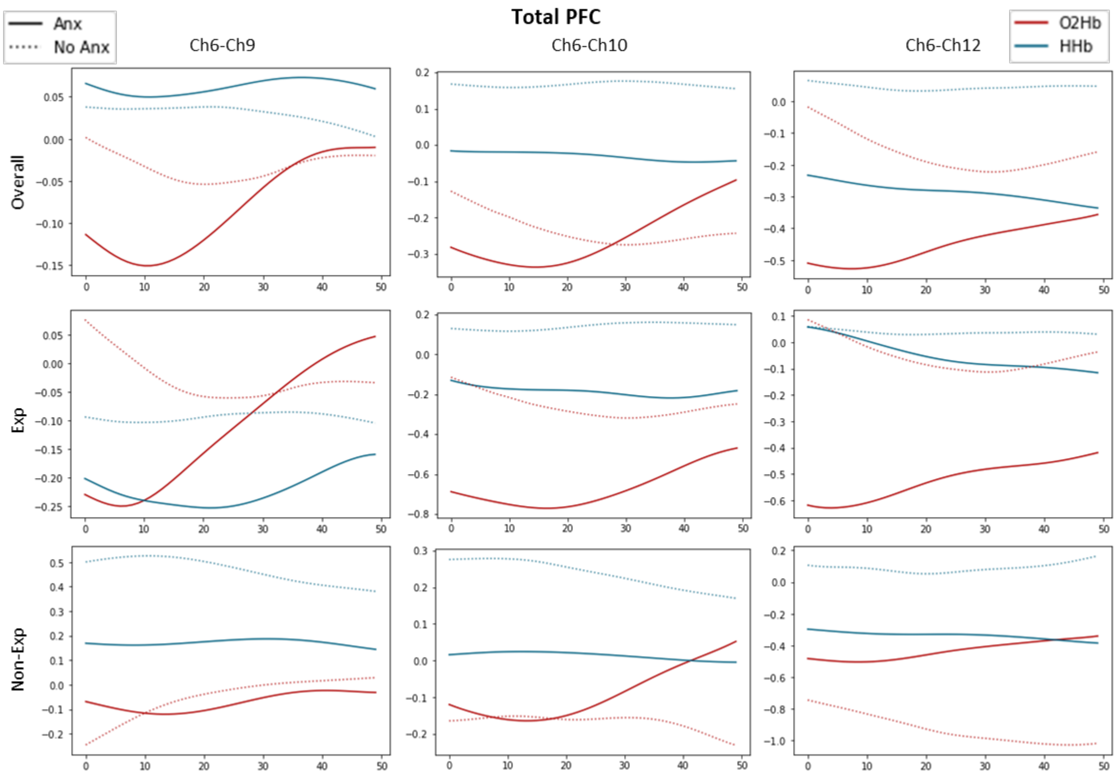

Figure C.14: Plots corresponding to the average total PFC activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. All channels-pairs with Ch6 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

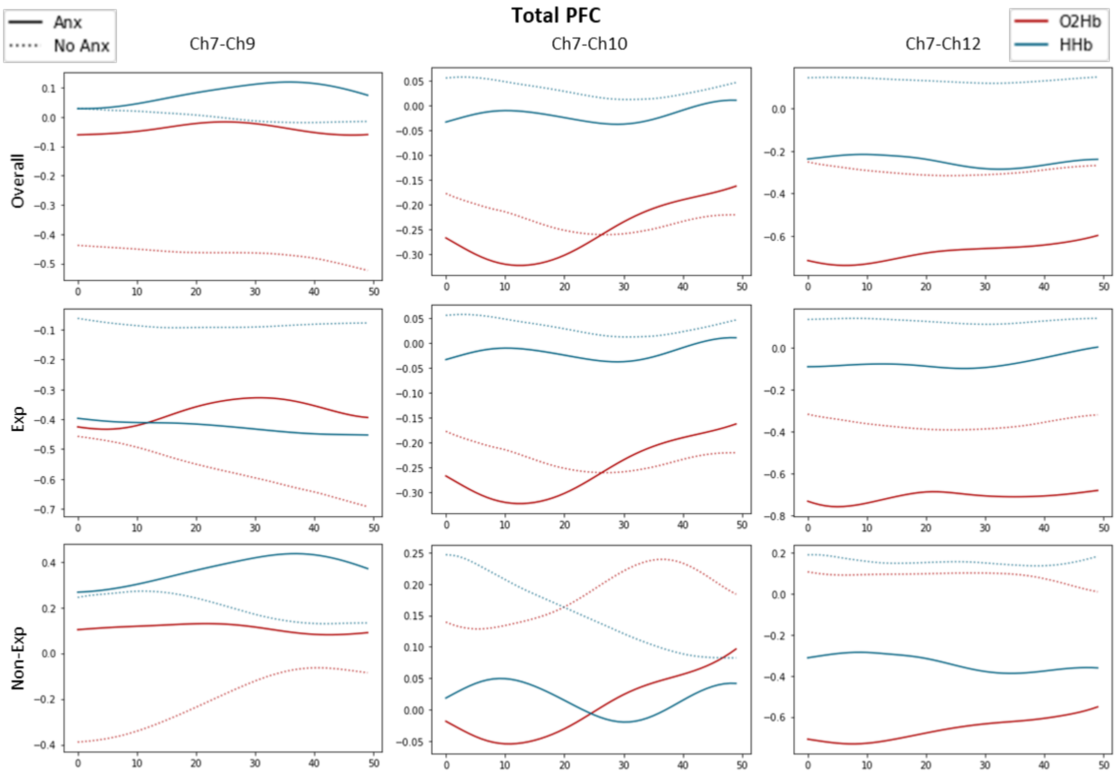

Figure C.15: Plots corresponding to the average total PFC activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. All channels-pairs with Ch7 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

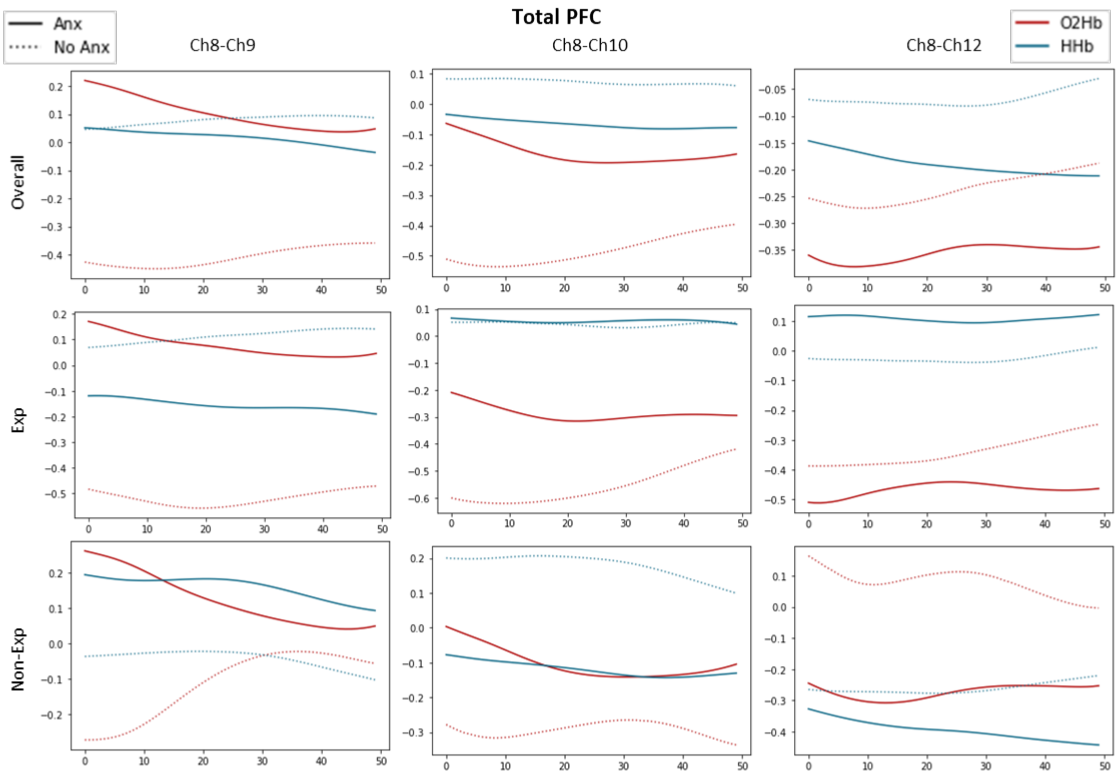

Figure C.16: Plots corresponding to the average total PFC activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. All channels-pairs with Ch8 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

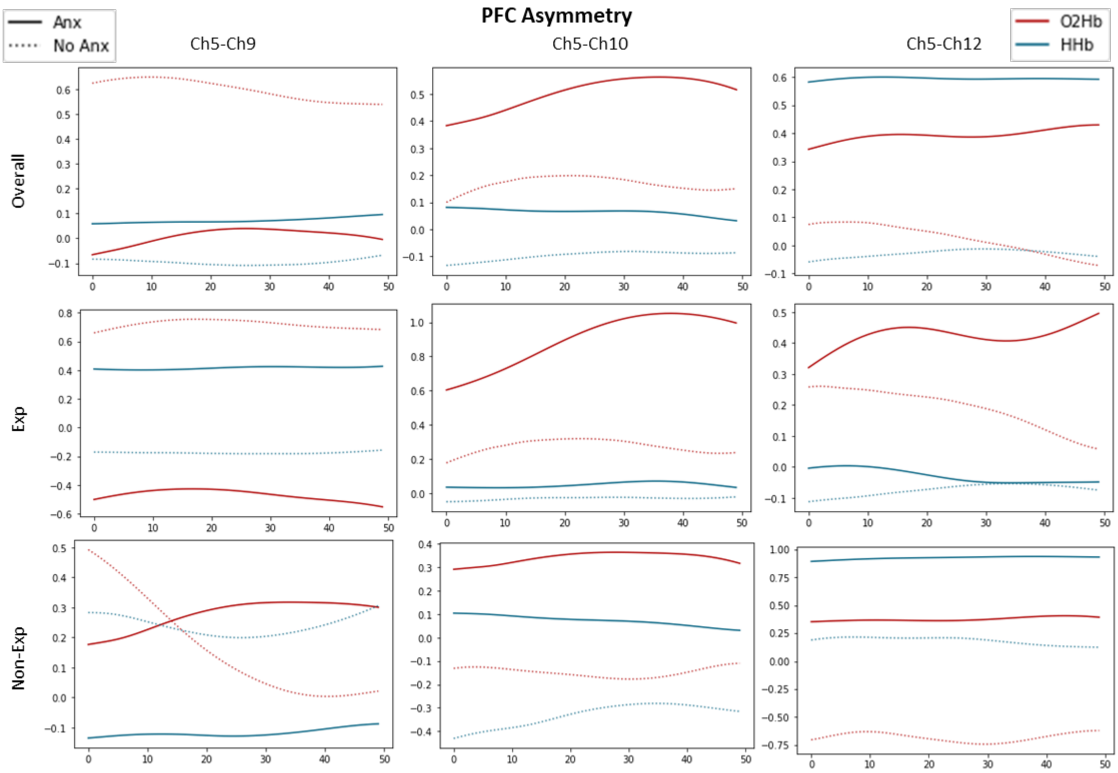

Figure C.17: Plots corresponding to the average PFC asymmetry activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. A positive asymmetry value indicates a higher right as compared to left PFC activation. All channels-pairs with Ch5 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

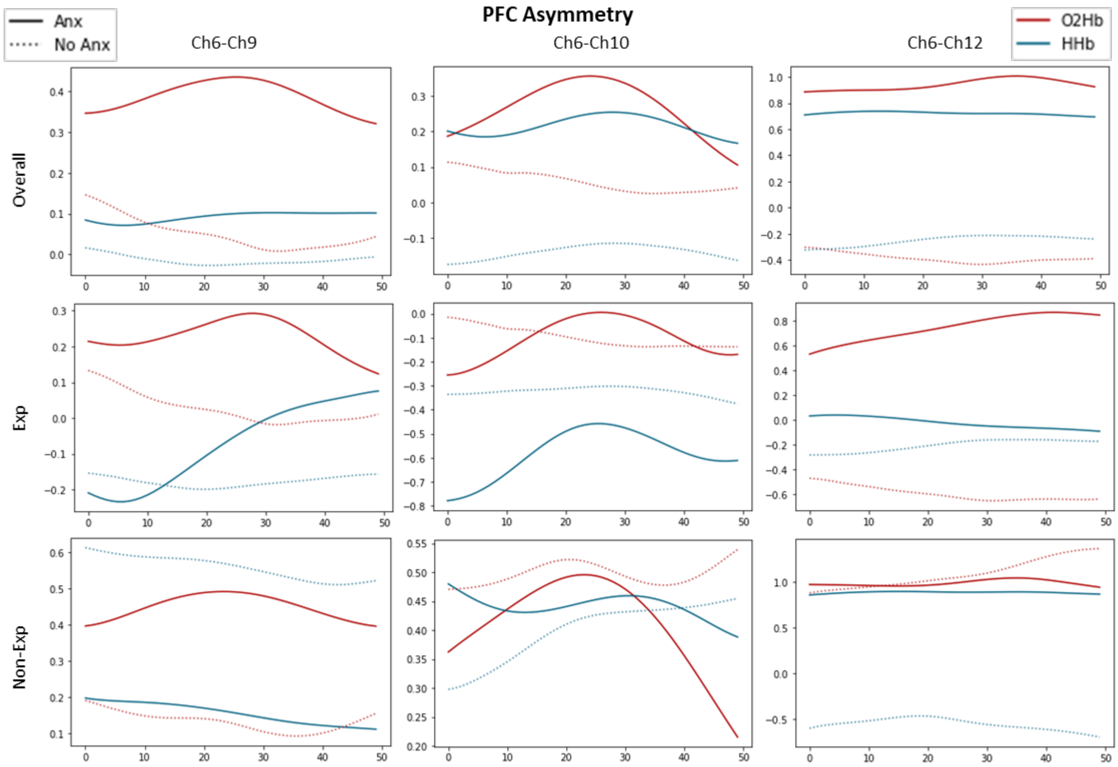

Figure C.18: Plots corresponding to the average PFC asymmetry activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. A positive asymmetry value indicates a higher right as compared to left PFC activation. All channels-pairs with Ch6 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

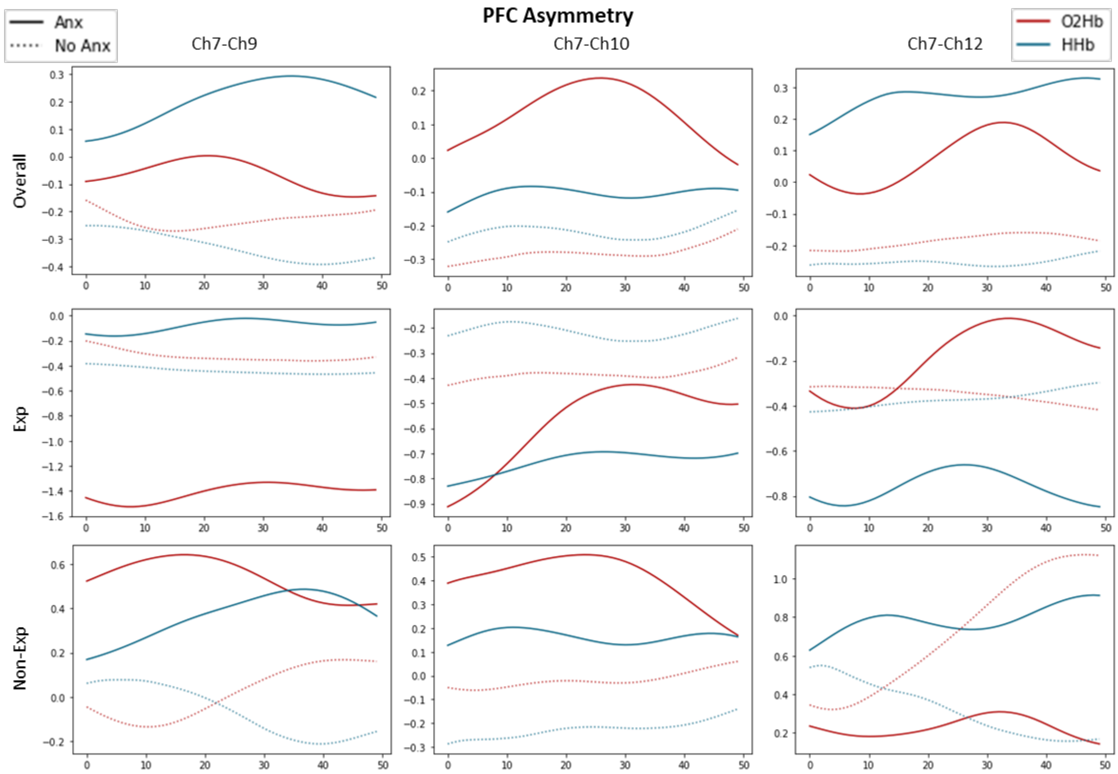

Figure C.19: Plots corresponding to the average PFC asymmetry activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. A positive asymmetry value indicates a higher right as compared to left PFC activation. All channels-pairs with Ch7 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

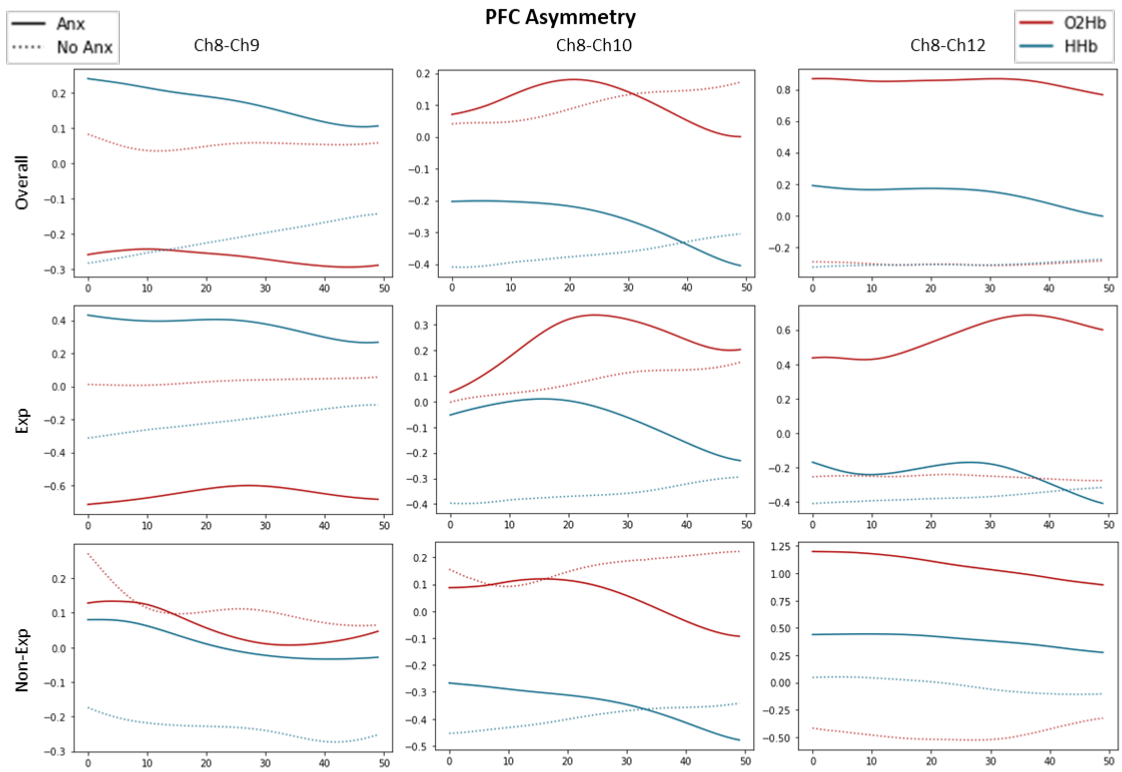

Figure C.20: Plots corresponding to the average PFC asymmetry activation for anxious and not anxious players. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. A positive asymmetry value indicates a higher right as compared to left PFC activation. All channels-pairs with Ch8 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Anxious players are represented by a solid line and not anxious players by a dotted line.

C.3 Goal vs No Goal

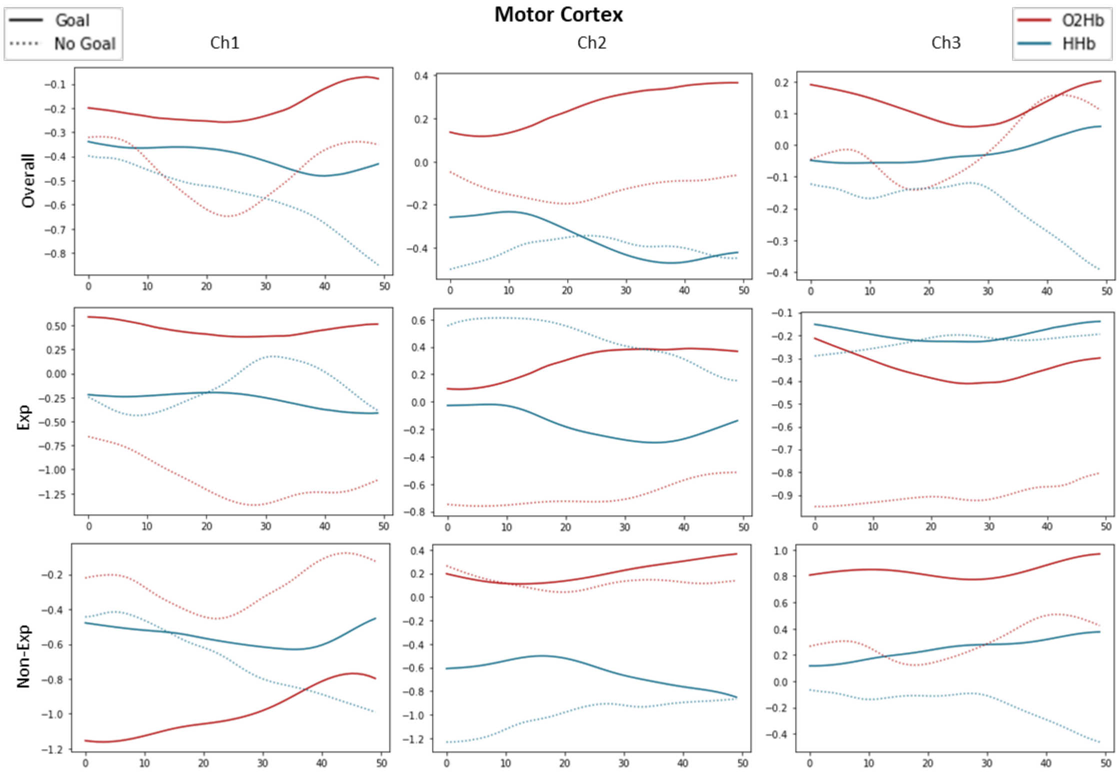

Figure C.21: Plots corresponding to the average motor cortex activation for scoring and missing penalties. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. From left to right the channels 1 to 3 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty is represented by a solid line and missing a penalty by a dotted line.

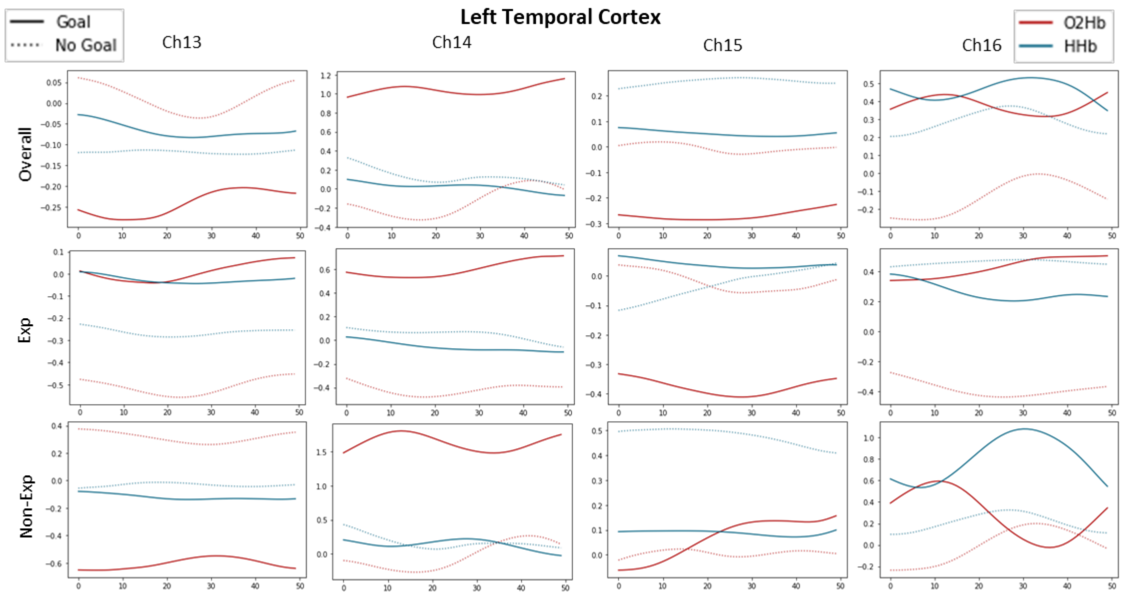

Figure C.22: Plots corresponding to the average left temporal cortex activation for scoring and missing penalties. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. From left to right the channels 13 to 16 are represented. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty is represented by a solid line and missing a penalty by a dotted line.

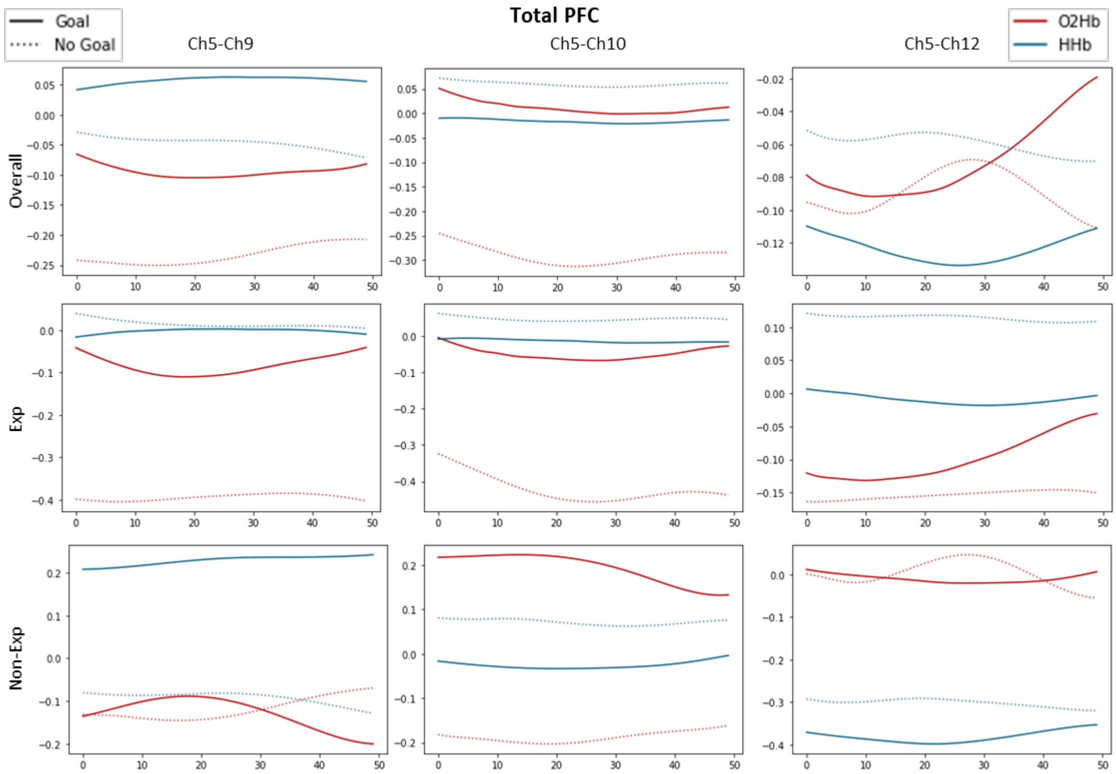

Figure C.23: Plots corresponding to the average total PFC activation for scoring and missing penalties. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. All channels-pairs with Ch5 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty is represented by a solid line and missing a penalty by a dotted line.

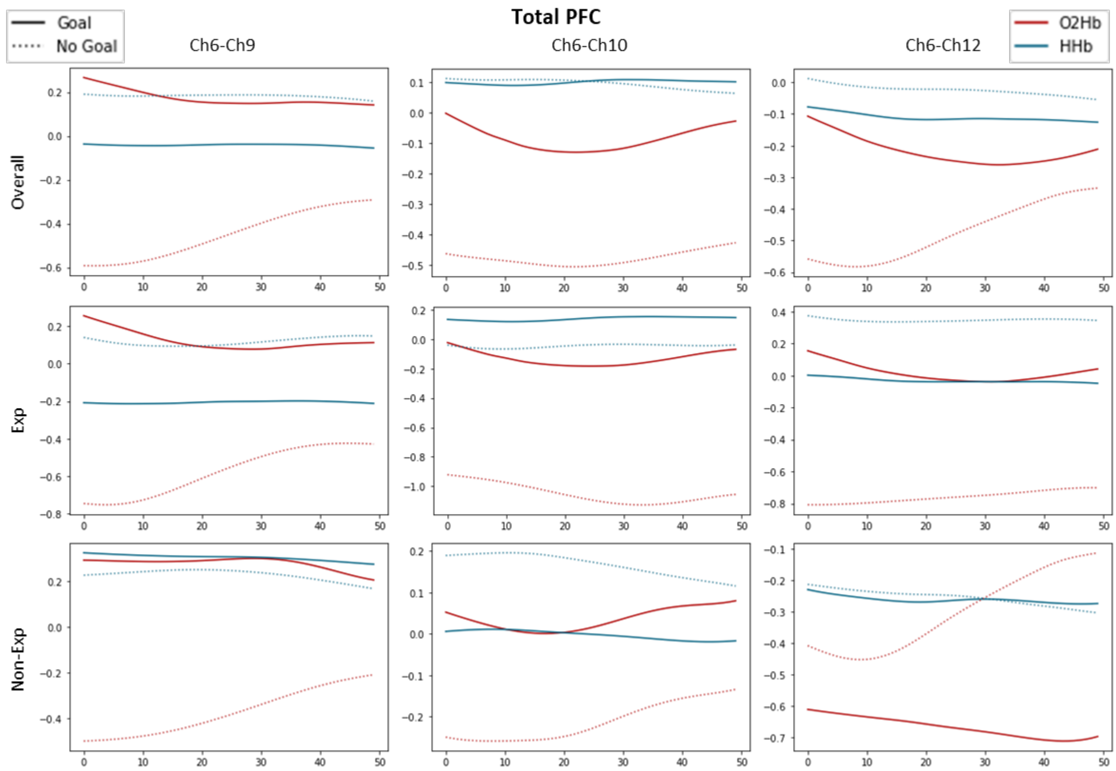

Figure C.24: Plots corresponding to the average total PFC activation for scoring and missing penalties. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. All channels-pairs with Ch6 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty is represented by a solid line and missing a penalty by a dotted line.

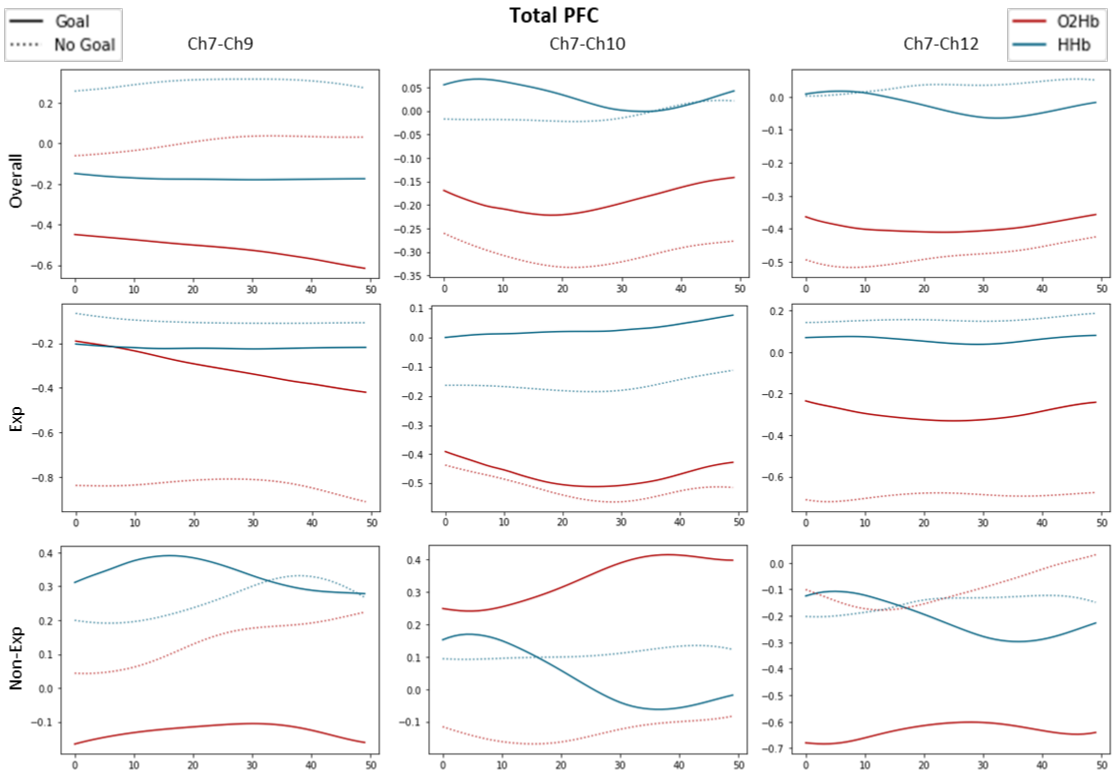

Figure C.25: Plots corresponding to the average total PFC activation for scoring and missing penalties. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. All channels-pairs with Ch7 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty is represented by a solid line and missing a penalty by a dotted line.

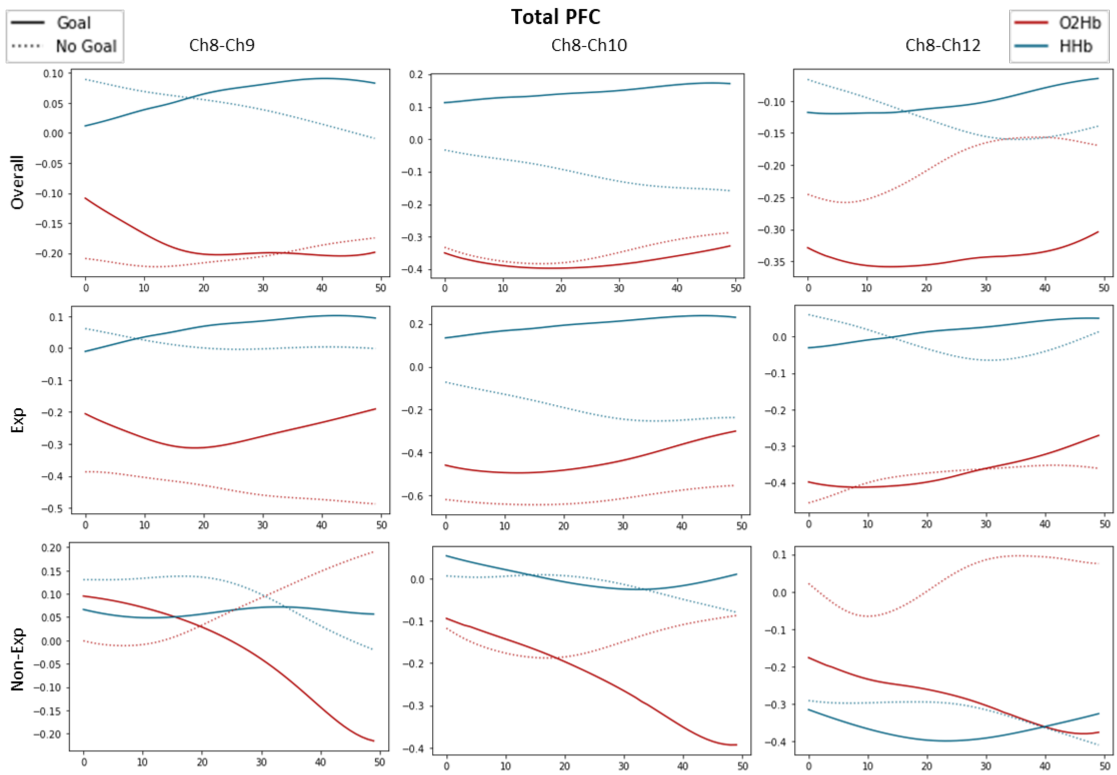

Figure C.26: Plots corresponding to the average total PFC activation for scoring and missing penalties. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. All channels-pairs with Ch8 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty is represented by a solid line and missing a penalty by a dotted line.

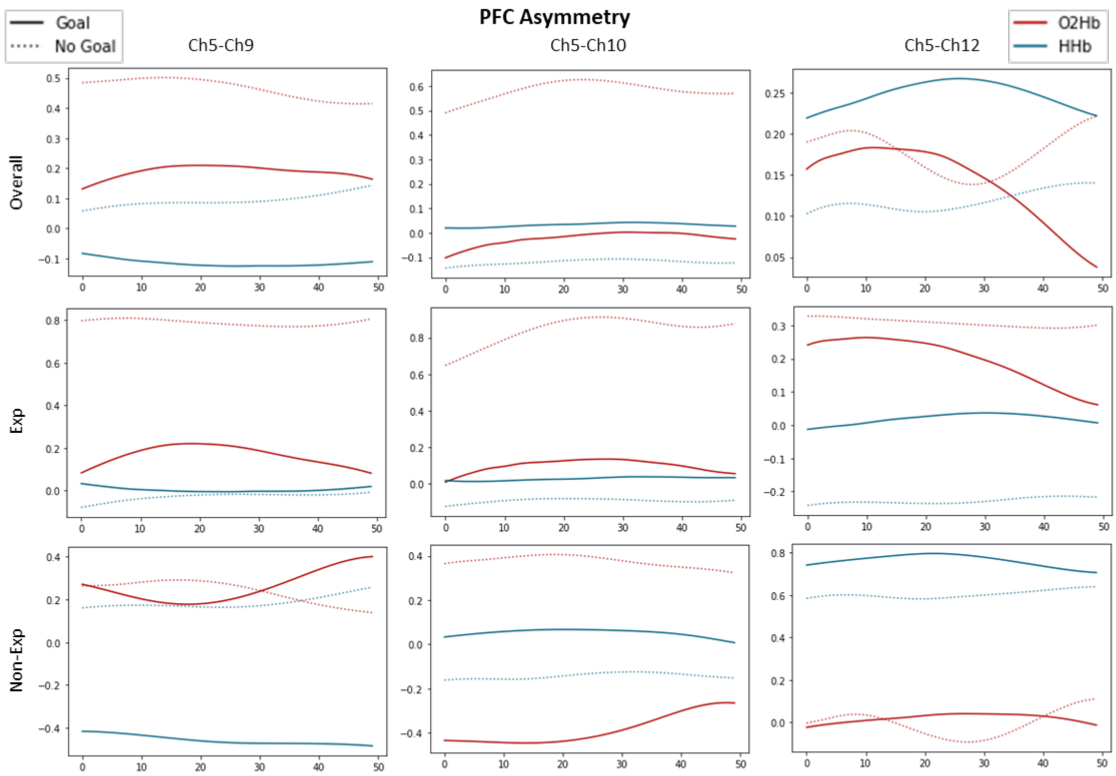

Figure C.27: Plots corresponding to the average PFC asymmetry activation for scoring and missing a penalty. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. A positive asymmetry value indicates a higher right as compared to left PFC activation. All channels-pairs with Ch5 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty represented by a solid line and missing a penalty by a dotted line.

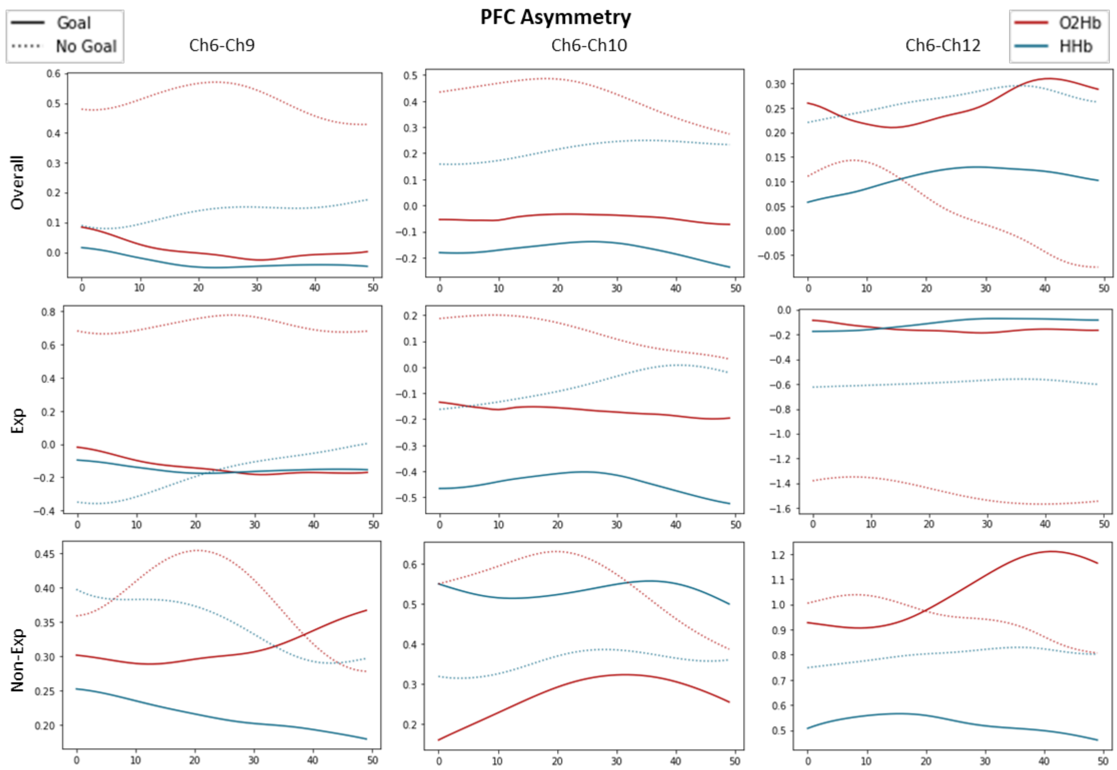

Figure C.28: Plots corresponding to the average PFC asymmetry activation for scoring and missing a penalty. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. A positive asymmetry value indicates a higher right as compared to left PFC activation. All channels-pairs with Ch6 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty represented by a solid line and missing a penalty by a dotted line.

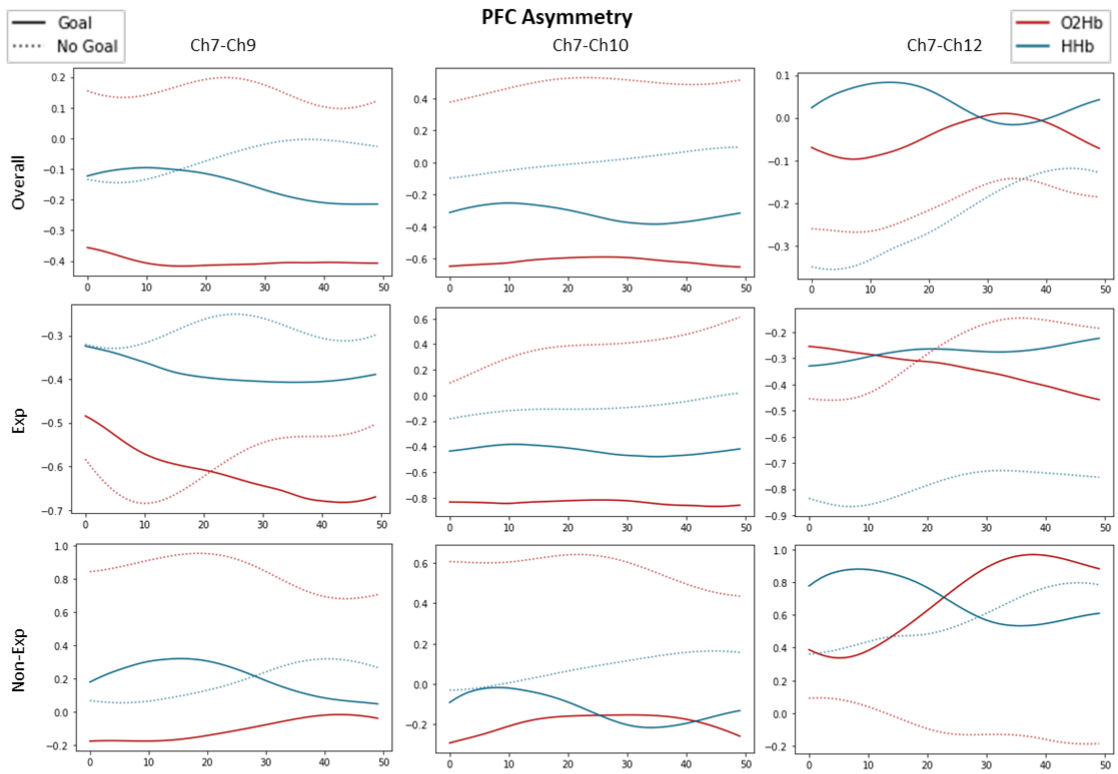

Figure C.29: Plots corresponding to the average PFC asymmetry activation for scoring and missing a penalty. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. A positive asymmetry value indicates a higher right as compared to left PFC activation. All channels-pairs with Ch7 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty represented by a solid line and missing a penalty by a dotted line.

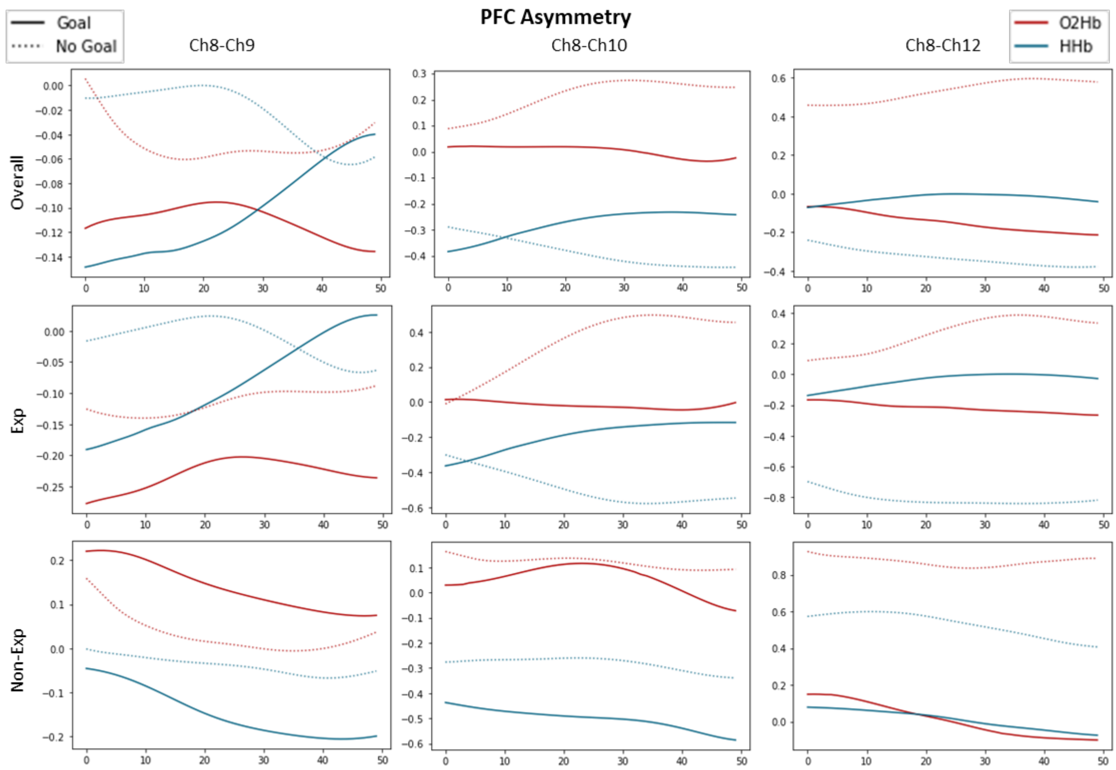

Figure C.30: Plots corresponding to the average PFC asymmetry activation for scoring and missing a penalty. The overall results (both experienced and inexperienced players) and the results for experienced and inexperienced players individually are shown. A positive asymmetry value indicates a higher right as compared to left PFC activation. All channels-pairs with Ch8 (right PFC) are included. Both O2Hb-concentrations (red) and HHb-concentrations (blue) are included. Scoring a penalty represented by a solid line and missing a penalty by a dotted line.

Appendix D

Tables of Brain Activity Results

D.1 Overall

Motor Cortex		Overall			
		Mean	Std	Min	Max
Ch1	HHb	-0.472	0.076	-0.608	-0.364
	O2Hb	-0.299	0.076	-0.409	-0.176
Ch2	HHb	-0.373	0.057	-0.443	-0.292
	O2Hb	0.118	0.067	0.029	0.212
Ch3	HHb	-0.086	0.011	-0.109	-0.066
	O2Hb	0.081	0.056	0.008	0.174

Table D.1: Results of the overall activation (all trails). Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure 5.2.

Total PFC		Overall			
		Mean	Std	Min	Max
Ch5-Ch9	HHb	0.008	0.004	-0.005	0.013
	O2Hb	-0.161	0.010	-0.175	-0.142
Ch5-Ch10	HHb	0.021	0.004	0.015	0.030
	O2Hb	-0.140	0.015	-0.155	-0.097
Ch5-Ch12	HHb	-0.099	0.004	-0.104	-0.087
	O2Hb	-0.077	0.140	-0.095	-0.053
Ch6-Ch9	HHb	0.043	0.005	0.026	0.049
	O2Hb	-0.054	0.026	-0.087	-0.016
Ch6-Ch10	HHb	0.099	0.005	0.087	0.105
	O2Hb	-0.243	0.031	-0.281	-0.186
Ch6-Ch12	HHb	-0.090	0.013	-0.109	-0.056
	O2Hb	-0.290	0.024	-0.315	-0.234
Ch7-Ch9	HHb	0.033	0.005	0.021	0.037
	O2Hb	-0.278	0.015	-0.317	-0.264
Ch7-Ch10	HHb	0.014	0.013	-0.006	0.033
	O2Hb	-0.240	0.022	-0.270	-0.201
Ch7-Ch12	HHb	-0.005	0.014	-0.028	0.014
	O2Hb	-0.424	0.017	-0.442	-0.380
Ch8-Ch9	HHb	0.055	0.006	0.040	0.062
	O2Hb	-0.195	0.013	-0.208	-0.154
Ch8-Ch10	HHb	0.025	0.010	0.012	0.042
	O2Hb	-0.361	0.025	-0.390	-0.309
Ch8-Ch12	HHb	-0.112	0.009	-0.124	-0.096
	O2Hb	-0.283	0.022	-0.314	-0.248

Table D.2: Results of the overall activation (all trails). Mean, standard deviation (std), the minimum values and the maximum values for each pair of channels regarding total PFC activation are given. This table is related to Figure 5.4.

Left Temp Cortex		Overall			
		Mean	Std	Min	Max
Ch13	HHb	-0.089	0.010	-0.099	-0.068
	O2Hb	-0.132	0.020	-0.158	-0.098
Ch14	HHb	0.069	0.050	-0.020	0.201
	O2Hb	0.487	0.080	0.404	0.626
Ch15	HHb	0.143	0.030	0.137	0.146
	O2Hb	-0.155	0.012	-0.173	-0.129
Ch16	HHb	0.390	0.048	0.294	0.461
	O2Hb	0.163	0.024	0.101	0.198

Table D.3: Results of the overall activation (all trails). Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure 5.3.

PFC Asymmetry		Overall			
		Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.017	0.009	-0.025	0.010
	O2Hb	0.323	0.020	0.285	0.349
Ch5-Ch10	HHb	-0.042	0.008	-0.060	-0.030
	O2Hb	0.280	0.030	0.194	0.310
Ch5-Ch12	HHb	0.199	0.009	0.175	0.208
	O2Hb	0.155	0.027	0.106	0.190
Ch6-Ch9	HHb	0.028	0.006	0.021	0.044
	O2Hb	0.189	0.022	0.154	0.228
Ch6-Ch10	HHb	-0.019	0.021	-0.051	0.011
	O2Hb	0.137	0.032	0.066	0.174
Ch6-Ch12	HHb	0.145	0.021	0.097	0.167
	O2Hb	0.195	0.013	0.179	0.218
Ch7-Ch 9	HHb	-0.113	0.011	-0.133	-0.097
	O2Hb	-0.157	0.014	-0.181	-0.128
Ch7-Ch10	HHb	-0.176	0.019	-0.217	-0.134
	O2Hb	-0.136	0.027	-0.202	-0.103
Ch7-Ch12	HHb	-0.062	0.021	-0.112	-0.020
	O2Hb	-0.099	0.040	-0.156	-0.043
Ch8-Ch 9	HHb	-0.067	0.009	-0.084	-0.049
	O2Hb	-0.082	0.008	-0.093	-0.061
Ch8-Ch10	HHb	-0.330	0.006	-0.339	-0.322
	O2Hb	0.105	0.026	0.052	0.137
Ch8-Ch12	HHb	-0.150	0.013	-0.180	-0.138
	O2Hb	0.136	0.008	0.116	0.151

Table D.4: Results of the overall activation (all trails). Mean, standard deviation (std), the minimum values and the maximum values for each pair of channels regarding the PFC asymmetry are given. This table is related to Figure 5.5.

D.2 Rounds

Motor Cortex		Round 1				Round 2				Round 3			
		Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	-0.393	0.116	-0.601	-0.231	-0.825	0.117	-0.948	-0.561	-0.260	0.156	-0.538	-0.027
	O2Hb	-1.018	0.086	-1.143	-0.887	0.298	0.093	0.187	0.467	-0.174	0.070	-0.270	-0.036
Ch2	HHb	-0.226	0.057	-0.364	-0.159	-0.248	0.014	-0.269	-0.226	-0.639	0.146	-0.831	-0.440
	O2Hb	0.043	0.105	-0.051	0.274	0.331	0.078	0.187	0.418	-0.036	0.187	-0.291	0.188
Ch3	HHb	0.132	0.082	0.043	0.281	-0.153	0.032	-0.204	-0.097	-0.210	0.080	-0.353	-0.122
	O2Hb	0.265	0.070	0.178	0.379	-0.027	0.048	-0.095	0.063	0.006	0.147	-0.181	0.242

Table D.5: Results of the activation per round. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure 5.2.

Left Temp Cortex		Round 1				Round 2				Round 3			
		Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	-0.106	0.011	-0.119	-0.082	-0.063	0.017	-0.087	-0.030	-0.101	0.024	-0.135	-0.069
	O2Hb	-0.113	0.046	-0.174	-0.052	-0.112	0.032	-0.149	-0.031	-0.180	0.025	-0.211	-0.130
Ch14	HHb	0.139	0.042	0.049	0.239	0.060	0.032	0.026	0.123	-0.006	0.098	-0.191	0.272
	O2Hb	1.238	0.073	1.141	1.405	-0.204	0.056	-0.283	-0.129	0.457	0.185	0.238	0.751
Ch15	HHb	0.062	0.010	0.051	0.086	0.133	0.005	0.126	0.143	0.230	0.018	0.195	0.253
	O2Hb	-0.164	0.023	-0.209	-0.132	-0.266	0.034	-0.310	-0.220	-0.015	0.029	-0.055	0.041
Ch16	HHb	0.651	0.066	0.555	0.749	0.734	0.119	0.549	0.888	-0.230	0.093	-0.419	-0.122
	O2Hb	0.384	0.083	0.262	0.504	0.130	0.029	0.068	0.163	-0.050	0.127	-0.213	0.126

Table D.6: Results of the activation per round. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure 5.3.

Total PFC		Round 1				Round 2				Round 3			
		Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	0.025	0.016	-0.006	0.040	-0.013	0.006	-0.024	-0.006	0.013	0.016	-0.018	0.040
	O2Hb	-0.058	0.032	-0.102	0.000	0.080	0.010	0.073	0.116	-0.392	0.040	-0.433	-0.325
Ch5-Ch10	HHb	-0.067	0.005	-0.071	-0.052	0.089	0.005	0.081	0.101	0.021	0.007	0.014	0.032
	O2Hb	-0.143	0.049	-0.196	-0.046	0.008	0.020	-0.019	0.072	-0.311	0.039	-0.348	-0.235
Ch5-Ch12	HHb	-0.149	0.021	-0.170	-0.103	-0.096	0.012	-0.110	-0.071	-0.050	0.013	-0.065	-0.025
	O2Hb	-0.321	0.007	-0.330	-0.305	0.066	0.006	0.056	0.081	-0.022	0.041	-0.085	0.035
Ch6-Ch9	HHb	0.026	0.010	0.008	0.038	-0.143	0.044	-0.204	-0.090	0.208	0.036	0.136	0.259
	O2Hb	-0.133	0.050	-0.183	-0.028	0.401	0.033	0.355	0.495	-0.354	0.086	-0.477	-0.233
Ch6-Ch10	HHb	-0.156	0.007	-0.166	-0.143	-0.060	0.011	-0.077	-0.047	0.509	0.019	0.467	0.525
	O2Hb	-0.566	0.029	-0.589	-0.482	0.232	0.043	0.186	0.358	-0.555	0.057	-0.599	-0.412
Ch6-Ch12	HHb	-0.175	0.031	-0.200	-0.098	-0.150	0.007	-0.156	-0.125	0.019	0.010	-0.009	0.035
	O2Hb	-0.733	0.090	-0.828	-0.525	-0.061	0.026	-0.080	0.018	-0.277	0.050	-0.337	-0.184
Ch7-Ch 9	HHb	0.020	0.036	-0.027	0.064	0.082	0.036	0.019	0.122	0.012	0.013	-0.007	0.031
	O2Hb	-0.299	0.028	-0.356	-0.238	-0.087	0.107	-0.225	0.095	-0.366	0.058	-0.485	-0.310
Ch7-Ch10	HHb	-0.103	0.037	-0.146	-0.042	0.119	0.024	0.079	0.158	0.003	0.022	-0.018	0.041
	O2Hb	-0.455	0.029	-0.488	-0.375	-0.056	0.042	-0.091	0.067	-0.232	0.064	-0.318	-0.111
Ch7-Ch12	HHb	-0.023	0.023	-0.049	-0.020	0.055	0.032	0.004	0.124	-0.042	0.005	-0.054	-0.034
	O2Hb	-0.573	0.036	-0.619	-0.488	-0.352	0.024	-0.380	-0.280	-0.352	0.067	-0.438	-0.251
Ch8-Ch 9	HHb	0.005	0.017	-0.032	0.022	0.070	0.017	0.044	0.094	0.078	0.025	0.029	0.110
	O2Hb	-0.107	0.073	-0.210	0.010	0.005	0.053	-0.039	0.153	-0.474	0.090	-0.608	-0.336
Ch8-Ch10	HHb	-0.119	0.013	-0.140	-0.095	0.005	0.019	-0.024	0.031	0.135	0.017	0.116	0.170
	O2Hb	-0.389	0.067	-0.467	-0.255	-0.108	0.030	-0.150	-0.070	-0.630	0.089	-0.730	-0.458
Ch8-Ch12	HHb	-0.205	0.018	-0.225	-0.166	-0.152	0.019	-0.177	-0.109	-0.002	0.020	-0.280	0.036
	O2Hb	-0.468	0.027	-0.512	-0.427	-0.148	0.010	-0.167	-0.134	-0.279	0.088	-0.377	-0.140

Table D.7: Results of the activation per round. Mean, standard deviation (std), the minimum values and the maximum values for each pair of channels regarding the total PFC activation are given. This table is related to Figure 5.4.

PFC Asymmetry		Round 1				Round 2				Round 3			
		Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.051	0.032	-0.080	0.012	0.026	0.012	0.011	0.047	-0.025	0.033	-0.080	0.036
	O2Hb	0.117	0.065	0.001	0.205	-0.161	0.020	-0.232	-0.145	0.784	0.080	0.650	0.866
Ch5-Ch10	HHb	0.134	0.010	0.104	0.142	-0.177	0.010	-0.202	-0.163	-0.043	0.014	-0.063	-0.027
	O2Hb	0.285	0.098	0.092	0.392	-0.016	0.040	-0.143	0.038	0.621	0.078	0.470	0.696
Ch5-Ch12	HHb	0.298	0.042	0.206	0.341	0.191	0.023	0.143	0.220	0.100	0.026	0.051	0.131
	O2Hb	0.642	0.014	0.610	0.661	-0.132	0.012	-0.162	-0.112	0.044	0.083	-0.071	0.169
Ch6-Ch9	HHb	-0.158	0.021	-0.181	-0.112	-0.284	0.023	-0.319	-0.256	0.413	0.009	0.403	0.438
	O2Hb	-0.681	0.023	-0.705	-0.614	0.260	0.038	0.186	0.332	0.713	0.075	0.581	0.821
Ch6-Ch10	HHb	0.046	0.018	0.020	0.074	-0.301	0.043	-0.384	-0.255	0.313	0.038	0.220	0.345
	O2Hb	0.137	0.071	0.019	0.213	0.378	0.044	0.272	0.431	-0.127	0.125	-0.342	0.077
Ch6-Ch12	HHb	-0.051	0.033	-0.131	-0.024	0.097	0.043	0.024	0.145	0.312	0.021	0.261	0.333
	O2Hb	0.288	0.054	0.229	0.387	0.927	0.033	0.826	0.965	-0.743	0.028	-0.788	-0.708
Ch7-Ch 9	HHb	-0.099	0.094	-0.223	0.014	-0.075	0.053	-0.159	-0.008	-0.146	0.048	-0.202	-0.073
	O2Hb	-0.741	0.062	-0.828	-0.664	-0.713	0.106	-0.854	-0.521	0.509	0.017	0.486	0.538
Ch7-Ch10	HHb	0.043	0.021	0.014	0.073	-0.182	0.050	-0.286	-0.054	-0.329	0.012	-0.345	-0.307
	O2Hb	-0.671	0.057	-0.793	-0.608	-0.118	0.022	-0.151	-0.060	0.261	0.053	0.142	0.329
Ch7-Ch12	HHb	-0.063	0.056	-0.142	0.017	0.253	0.059	0.102	0.374	-0.332	0.051	-0.396	-0.258
	O2Hb	0.257	0.058	0.159	0.319	0.216	0.049	0.118	0.287	-0.756	0.044	-0.850	-0.713
Ch8-Ch 9	HHb	-0.133	0.047	-0.186	-0.054	0.192	0.030	0.128	0.219	-0.254	0.033	-0.299	-0.194
	O2Hb	-0.279	0.024	-0.324	-0.246	-0.351	0.025	-0.388	-0.299	0.358	0.047	0.312	0.462
Ch8-Ch10	HHb	-0.201	0.029	-0.268	-0.172	-0.109	0.023	-0.157	-0.082	-0.632	0.008	-0.645	-0.623
	O2Hb	0.098	0.039	0.038	0.152	-0.340	0.074	-0.482	-0.250	0.626	0.043	0.568	0.683
Ch8-Ch12	HHb	-0.161	0.055	-0.243	-0.090	-0.119	0.037	-0.170	-0.073	-0.173	0.026	-0.229	-0.146
	O2Hb	0.173	0.075	0.065	0.285	0.312	0.029	0.266	0.357	-0.137	0.030	-0.207	-0.079

Table D.8: Results of the activation per round. Mean, standard deviation (std), the minimum values and the maximum values for each pair of channels regarding the PFC asymmetry are given. This table is related to Figure 5.5.

D.3 Exp vs Non-Exp

Motor Cortex

Motor Cortex		Overall - Exp				Overall - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	-0.248	0.068	-0.407	-0.150	-0.629	0.117	-0.761	-0.453
	O2Hb	0.129	0.095	0.015	0.327	-0.617	0.114	-0.742	-0.412
Ch2	HHb	0.005	0.105	-0.113	0.156	-0.804	0.050	-0.895	-0.730
	O2Hb	0.067	0.101	-0.101	0.176	0.166	0.054	0.086	0.255
Ch3	HHb	-0.200	0.023	-0.222	-0.149	0.020	0.038	-0.072	0.079
	O2Hb	-0.442	0.045	-0.502	-0.344	0.577	0.083	0.476	0.720

Table D.9: Results of the overall activation (all trails) for experienced and inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.1.

Motor Cortex		Round 1 - Exp				Round 1 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	-0.511	0.136	-0.723	-0.315	-0.250	0.152	-0.559	-0.073
	O2Hb	-0.776	0.094	-0.879	-0.573	-1.290	0.137	-1.450	-1.025
Ch2	HHb	-0.055	0.040	-0.135	-0.002	-0.342	0.099	-0.607	-0.234
	O2Hb	-0.182	0.088	-0.332	-0.066	0.213	0.144	0.062	0.571
Ch3	HHb	-0.550	0.071	-0.629	-0.425	1.042	0.099	0.904	1.224
	O2Hb	-0.645	0.122	-0.775	-0.374	1.389	0.055	1.308	1.528

Table D.10: Results of the activation for experienced and inexperienced players during the first round. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.1.

Motor Cortex		Round 2 - Exp				Round 2 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	-1.000	0.107	-1.146	-0.845	-0.728	0.214	-0.986	-0.354
	O2Hb	0.751	0.123	0.609	0.967	0.051	0.182	-0.173	0.361
Ch2	HHb	0.560	0.065	0.374	0.617	-1.099	0.067	-1.184	-0.906
	O2Hb	0.306	0.102	0.190	0.545	0.352	0.128	0.069	0.492
Ch3	HHb	-0.259	0.023	-0.291	-0.219	-0.074	0.065	-0.170	0.042
	O2Hb	-0.048	0.068	-0.127	0.097	-0.010	0.044	-0.085	0.038

Table D.11: Results of the activation for experienced and inexperienced players during the second round. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.1.

Motor Cortex		Round 3 - Exp				Round 3 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	0.663	0.086	0.468	0.827	-0.758	0.203	-1.080	-0.482
	O2Hb	0.809	0.105	0.639	0.997	-0.813	0.051	-0.884	-0.706
Ch2	HHb	-0.424	0.233	-0.704	-0.061	-1.070	0.136	-1.345	-0.877
	O2Hb	0.052	0.266	-0.453	0.301	-0.158	0.181	-0.430	-0.103
Ch3	HHb	0.249	0.041	0.194	0.331	-0.603	0.140	-0.888	-0.470
	O2Hb	-0.578	0.082	-0.693	-0.395	0.507	0.214	0.198	0.847

Table D.12: Results of the activation for experienced and inexperienced players during the third round. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.1.

Left Temporal Cortex

Left Temp Cortex		Overall - Exp				Overall - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	-0.106	0.015	-0.123	-0.070	-0.073	0.009	-0.084	-0.060
	O2Hb	-0.162	0.035	-0.207	-0.099	-0.102	0.006	-0.110	-0.089
Ch14	HHb	-0.024	0.036	-0.087	0.052	0.153	0.065	0.040	0.335
	O2Hb	0.296	0.056	0.229	0.383	0.633	0.101	0.531	0.812
Ch15	HHb	0.017	0.010	0.008	0.040	0.333	0.022	0.293	0.353
	O2Hb	-0.268	0.026	-0.303	-0.219	0.029	0.028	-0.036	0.059
Ch16	HHb	0.313	0.038	0.275	0.394	0.467	0.125	0.300	0.648
	O2Hb	0.208	0.041	0.161	0.270	0.116	0.033	0.021	0.158

Table D.13: Results of the overall activation (all trails) for experienced and inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.2.

Left Temp Cortex		Round 1 - Exp				Round 1 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	-0.099	0.019	-0.122	-0.063	-0.114	0.013	-0.131	-0.096
	O2Hb	-0.142	0.047	-0.197	-0.054	-0.080	0.059	-0.197	-0.014
Ch14	HHb	0.056	0.035	0.013	0.143	0.215	0.084	0.016	0.326
	O2Hb	0.590	0.085	0.502	0.751	1.778	0.140	1.574	1.992
Ch15	HHb	0.066	0.013	0.049	0.099	0.058	0.014	0.037	0.090
	O2Hb	-0.305	0.042	-0.361	-0.223	0.033	0.068	-0.080	0.111
Ch16	HHb	0.360	0.074	0.274	0.524	0.985	0.198	0.715	1.264
	O2Hb	0.494	0.041	0.442	0.550	0.244	0.232	-0.094	0.579

Table D.14: Results of the activation for experienced and inexperienced players during the first round. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.2.

Left Temp Cortex		Round 2 - Exp				Round 2 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	0.065	0.020	0.036	0.099	-0.184	0.016	-0.206	-0.151
	O2Hb	0.152	0.034	0.113	0.242	-0.362	0.030	-0.398	-0.289
Ch14	HHb	0.041	0.010	0.012	0.050	0.077	0.063	0.019	0.210
	O2Hb	0.151	0.031	0.107	0.218	-0.501	0.118	-0.666	-0.354
Ch15	HHb	0.010	0.013	-0.004	0.033	0.441	0.034	0.398	0.503
	O2Hb	-0.500	0.044	-0.547	-0.416	0.319	0.036	0.253	0.361
Ch16	HHb	0.362	0.016	0.331	0.400	1.068	0.220	0.735	1.364
	O2Hb	-0.027	0.013	-0.044	0.024	0.287	0.058	0.154	0.349

Table D.15: Results of the activation for experienced and inexperienced players during the second round. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.2.

Left Temp Cortex		Round 3 - Exp				Round 3 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	-0.341	0.033	-0.390	-0.294	0.140	0.028	0.096	0.182
	O2Hb	-0.574	0.062	-0.635	-0.465	0.165	0.048	0.106	0.264
Ch14	HHb	-0.205	0.122	-0.471	-0.004	0.193	0.116	0.033	0.548
	O2Hb	0.119	0.112	-0.028	0.282	0.665	0.232	0.392	1.045
Ch15	HHb	-0.032	0.014	-0.056	-0.016	0.479	0.032	0.402	0.515
	O2Hb	0.106	0.030	0.062	0.171	-0.135	0.031	-0.175	-0.079
Ch16	HHb	0.209	0.048	0.093	0.285	-0.648	0.141	-0.906	-0.469
	O2Hb	0.056	0.078	-0.029	0.173	-0.152	0.489	-0.399	0.123

Table D.16: Results of the activation for experienced and inexperienced players during the third round. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.2.

Total PFC

Total PFC		Overall - Exp				Overall - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	0.004	0.002	-0.005	0.006	0.015	0.007	-0.005	0.024
	O2Hb	-0.190	0.014	-0.208	-0.164	-0.122	0.006	-0.132	-0.111
Ch5-Ch10	HHb	0.009	0.004	0.004	0.018	0.041	0.006	0.033	0.051
	O2Hb	-0.187	0.023	-0.212	-0.123	-0.069	0.004	-0.075	-0.058
Ch5-12	HHb	0.033	0.005	0.027	0.045	-0.345	0.004	-0.351	-0.335
	O2Hb	-0.117	0.024	-0.141	-0.071	-0.005	0.010	-0.023	0.008
Ch6-Ch 9	HHb	-0.119	0.008	-0.131	-0.109	0.264	0.018	0.219	0.278
	O2Hb	-0.045	0.025	-0.079	0.015	-0.065	0.044	-0.125	-0.011
Ch6-Ch10	HHb	0.098	0.012	0.078	0.112	0.100	0.020	0.064	0.123
	O2Hb	-0.338	0.045	-0.391	-0.225	-0.120	0.037	-0.160	-0.054
Ch6-Ch12	HHb	0.027	0.012	0.012	0.059	-0.260	0.015	-0.285	-0.224
	O2Hb	-0.126	0.040	-0.169	-0.021	-0.516	0.033	-0.559	-0.454
Ch7-Ch 9	HHb	-0.173	0.007	-0.179	-0.149	0.299	0.018	0.258	0.317
	O2Hb	-0.520	0.047	-0.616	-0.449	0.004	0.034	-0.061	0.037
Ch7-Ch10	HHb	-0.039	0.019	-0.057	0.011	0.078	0.032	0.040	0.127
	O2Hb	-0.486	0.034	-0.529	-0.407	0.079	0.043	0.025	0.133
Ch7-Ch12	HHb	0.093	0.011	0.075	0.116	-0.186	0.029	-0.226	-0.146
	O2Hb	-0.425	0.019	-0.445	-0.384	-0.421	0.032	-0.469	-0.372
Ch8-Ch 9	HHb	0.043	0.013	0.020	0.060	0.078	0.027	0.014	0.101
	O2Hb	-0.333	0.022	-0.359	-0.278	0.026	0.010	0.005	0.043
Ch8-Ch10	HHb	0.046	0.006	0.035	0.054	-0.010	0.022	-0.047	0.024
	O2Hb	-0.499	0.050	-0.549	-0.393	-0.179	0.024	-0.200	-0.109
Ch8-Ch12	HHb	0.003	0.012	-0.010	0.036	-0.349	0.016	-0.365	-0.305
	O2Hb	-0.373	0.036	-0.420	-0.304	-0.129	0.018	-0.152	-0.078

Table D.17: Results of the overall activation (all trails) for experienced and inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.3 to C.6.

Total PFC		Round 1 - Exp				Round 1 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.135	0.017	-0.169	-0.118	0.231	0.016	0.203	0.253
	O2Hb	-0.024	0.037	-0.061	0.068	-0.102	0.037	-0.171	-0.065
Ch5-Ch10	HHb	-0.040	0.003	-0.044	-0.035	-0.121	0.013	-0.133	-0.083
	O2Hb	-0.349	0.057	-0.410	-0.223	0.218	0.044	0.143	0.263
Ch5-12	HHb	-0.151	0.022	-0.180	-0.109	-0.147	0.023	-0.170	-0.095
	O2Hb	-0.583	0.008	-0.596	-0.560	-0.002	0.016	-0.018	0.050
Ch6-Ch 9	HHb	-0.185	0.011	-0.215	-0.172	0.177	0.011	0.164	0.192
	O2Hb	-0.391	0.137	-0.521	-0.077	0.051	0.015	0.007	0.066
Ch6-Ch10	HHb	-0.114	0.008	-0.121	-0.092	-0.183	0.007	-0.194	-0.173
	O2Hb	-0.858	0.111	-0.962	-0.596	-0.384	0.029	-0.421	-0.347
Ch6-Ch12	HHb	-0.262	0.077	-0.360	-0.093	-0.121	0.011	-0.140	-0.097
	O2Hb	-0.782	0.236	-1.081	-0.283	-0.703	0.016	-0.726	-0.670
Ch7-Ch 9	HHb	-0.153	0.010	-0.174	-0.128	0.136	0.056	0.062	0.204
	O2Hb	-0.492	0.095	-0.627	-0.282	-0.159	0.026	-0.207	-0.126
Ch7-Ch10	HHb	-0.087	0.007	-0.099	-0.074	-0.116	0.063	-0.194	-0.006
	O2Hb	-0.906	0.095	-0.997	-0.691	0.030	0.057	-0.048	0.099
Ch7-Ch12	HHb	0.129	0.019	0.107	0.165	-0.174	0.031	-0.221	-0.124
	O2Hb	-0.575	0.070	-0.651	-0.412	-0.570	0.014	-0.597	-0.555
Ch8-Ch 9	HHb	-0.072	0.026	-0.133	-0.046	0.083	0.010	0.067	0.099
	O2Hb	-0.125	0.058	-0.182	0.030	-0.093	0.094	-0.254	0.005
Ch8-Ch10	HHb	-0.086	0.030	-0.145	-0.058	-0.152	0.010	-0.164	-0.126
	O2Hb	-0.514	0.046	-0.568	-0.405	-0.278	0.099	-0.426	-0.121
Ch8-Ch12	HHb	0.016	0.028	-0.035	0.048	-0.400	0.018	-0.421	-0.355
	O2Hb	-0.716	0.010	-0.737	-0.703	-0.269	0.043	-0.333	-0.203

Table D.18: Results of the activation for experienced and inexperienced players during the first round. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.3 to C.6.

Total PFC		Round 2 - Exp				Round 2 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	0.038	0.004	0.025	0.043	-0.144	0.020	-0.178	-0.122
	O2Hb	-0.005	0.020	-0.025	0.057	0.303	0.018	0.270	0.325
Ch5-Ch10	HHb	0.055	0.006	0.043	0.069	0.156	0.009	0.145	0.178
	O2Hb	0.033	0.020	0.001	0.098	-0.042	0.019	-0.063	0.020
Ch5-12	HHb	-0.007	0.015	-0.024	0.019	-0.272	0.006	-0.286	-0.253
	O2Hb	0.023	0.028	0.000	0.088	0.152	0.045	0.049	0.200
Ch6-Ch 9	HHb	-0.250	0.041	-0.307	-0.192	0.153	0.053	0.078	0.217
	O2Hb	0.402	0.045	0.354	0.528	0.401	0.057	0.315	0.481
Ch6-Ch10	HHb	-0.141	0.027	-0.182	-0.112	0.045	0.011	0.022	0.060
	O2Hb	0.550	0.053	0.493	0.701	-0.148	0.035	-0.184	-0.054
Ch6-Ch12	HHb	-0.171	0.013	-0.186	-0.146	-0.111	0.033	-0.175	-0.039
	O2Hb	0.286	0.032	0.252	0.366	-0.547	0.029	-0.586	-0.469
Ch7-Ch 9	HHb	-0.252	0.045	-0.304	-0.187	1.084	0.268	0.635	1.387
	O2Hb	0.016	0.138	-0.173	0.222	-0.398	0.038	-0.442	-0.286
Ch7-Ch10	HHb	0.089	0.019	0.060	0.137	0.156	0.032	0.103	0.200
	O2Hb	-0.022	0.048	-0.070	0.106	-0.108	0.037	-0.141	0.008
Ch7-Ch12	HHb	0.155	0.026	0.116	0.222	-0.146	0.057	-0.238	-0.071
	O2Hb	-0.307	0.030	-0.351	-0.241	-0.460	0.031	-0.509	-0.372
Ch8-Ch 9	HHb	0.116	0.023	0.076	0.151	-0.117	0.021	-0.180	-0.085
	O2Hb	-0.170	0.061	-0.217	-0.017	0.565	0.039	0.498	0.697
Ch8-Ch10	HHb	0.008	0.021	-0.020	0.039	0.000	0.019	-0.038	0.020
	O2Hb	-0.084	0.050	-0.146	-0.010	-0.150	0.031	-0.183	-0.034
Ch8-Ch12	HHb	-0.087	0.027	-0.121	-0.018	-0.324	0.022	-0.351	-0.251
	O2Hb	-0.188	0.012	-0.209	-0.154	-0.052	0.049	-0.136	0.024

Table D.19: Results of the activation for experienced and inexperienced players during the second round. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.3 to C.6.

Total PFC		Round 3 - Exp Mean	Std	Min	Max	Round 3 - Non-Exp Mean	Std	Min	Max
Ch5-Ch9	HHb	0.066	0.012	0.055	0.091	-0.045	0.024	-0.096	-0.015
	O2Hb	-0.488	0.049	-0.547	-0.419	-0.296	0.034	-0.332	-0.227
Ch5-Ch10	HHb	-0.003	0.004	-0.008	0.004	0.051	0.013	0.030	0.066
	O2Hb	-0.342	0.048	-0.394	-0.249	-0.282	0.032	-0.332	-0.222
Ch5-12	HHb	0.261	0.013	0.248	0.288	-0.795	0.017	-0.822	-0.777
	O2Hb	0.082	0.047	0.007	0.154	-0.293	0.028	-0.334	-0.262
Ch6-Ch 9	HHb	0.058	0.026	0.019	0.114	0.396	0.054	0.282	0.447
	O2Hb	-0.319	0.094	-0.454	-0.206	-0.398	0.077	-0.508	-0.263
Ch6-Ch10	HHb	0.445	0.006	0.436	0.456	0.664	0.062	0.542	0.726
	O2Hb	-0.914	0.038	-0.960	-0.811	0.281	0.139	0.093	0.519
Ch6-Ch12	HHb	0.313	0.009	0.292	0.328	-0.569	0.017	-0.611	-0.550
	O2Hb	-0.304	0.043	-0.351	-0.203	-0.215	0.076	-0.312	-0.116
Ch7-Ch 9	HHb	-0.120	0.030	-0.160	-0.073	0.192	0.014	0.151	0.214
	O2Hb	-0.963	0.060	-1.076	-0.896	0.231	0.057	0.106	0.282
Ch7-Ch10	HHb	-0.117	0.038	-0.159	-0.047	0.203	0.013	0.185	0.223
	O2Hb	-0.611	0.054	-0.670	-0.492	0.273	0.080	0.152	0.396
Ch7-Ch12	HHb	0.027	0.007	0.018	0.042	-0.249	0.032	-0.337	-0.210
	O2Hb	-0.425	0.062	-0.506	-0.322	-0.096	0.084	-0.215	0.008
Ch8-Ch 9	HHb	0.024	0.008	0.015	0.042	0.171	0.068	0.027	0.228
	O2Hb	-0.671	0.086	-0.806	-0.550	-0.178	0.097	-0.312	-0.010
Ch8-Ch10	HHb	0.142	0.010	0.130	0.164	0.119	0.049	0.022	0.184
	O2Hb	-1.017	0.099	-1.136	-0.822	-0.098	0.077	-0.171	0.042
Ch8-Ch12	HHb	0.082	0.013	0.068	0.112	-0.286	0.054	-0.397	-0.222
	O2Hb	-0.403	0.103	-0.521	-0.236	0.044	0.049	-0.016	0.119

Table D.20: Results of the activation for experienced and inexperienced players during the third round. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.3 to C.6.

PFC Asymmetry

PFC Asymmetry		Overall - Exp				Overall - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.008	0.005	-0.011	0.009	-0.029	0.015	-0.047	0.010
	O2Hb	0.379	0.029	0.328	0.417	0.244	0.013	0.222	0.265
Ch5-Ch10	HHb	-0.017	0.008	-0.035	-0.009	-0.083	0.011	-0.102	-0.067
	O2Hb	0.375	0.045	0.246	0.424	0.139	0.008	0.117	0.150
Ch5-12	HHb	-0.065	0.011	-0.091	-0.053	0.691	0.008	0.671	0.701
	O2Hb	0.234	0.048	0.141	0.282	0.010	0.019	-0.016	0.045
Ch6-Ch 9	HHb	-0.158	0.026	-0.188	-0.112	0.283	0.030	0.241	0.329
	O2Hb	0.067	0.034	0.029	0.149	0.349	0.021	0.319	0.379
Ch6-Ch10	HHb	-0.359	0.026	-0.407	-0.323	0.425	0.018	0.397	0.449
	O2Hb	-0.100	0.027	-0.145	-0.062	0.445	0.048	0.337	0.505
Ch6-Ch12	HHb	-0.185	0.036	-0.246	-0.149	0.625	0.018	0.585	0.649
	O2Hb	-0.395	0.033	-0.432	-0.322	1.006	0.043	0.959	1.072
Ch7-Ch 9	HHb	-0.367	0.011	-0.384	-0.323	0.193	0.026	0.125	0.221
	O2Hb	-0.606	0.022	-0.624	-0.524	0.366	0.027	0.331	0.407
Ch7-Ch10	HHb	-0.314	0.021	-0.349	-0.267	-0.010	0.018	-0.058	0.028
	O2Hb	-0.418	0.038	-0.513	-0.350	0.230	0.045	0.123	0.283
Ch7-Ch12	HHb	-0.445	0.032	-0.500	-0.401	0.644	0.036	0.586	0.693
	O2Hb	-0.319	0.021	-0.369	-0.291	0.385	0.109	0.235	0.524
Ch8-Ch 9	HHb	-0.055	0.033	-0.117	-0.012	-0.089	0.035	-0.130	-0.022
	O2Hb	-0.184	0.019	-0.217	-0.162	0.080	0.044	0.037	0.187
Ch8-Ch10	HHb	-0.310	0.015	-0.339	-0.284	-0.363	0.029	-0.429	-0.335
	O2Hb	0.113	0.049	0.005	0.163	0.095	0.030	0.033	0.128
Ch8-Ch12	HHb	-0.341	0.030	-0.363	-0.327	0.243	0.056	0.142	0.305
	O2Hb	-0.041	0.023	-0.073	-0.010	0.440	0.052	0.390	0.537

Table D.21: Results of the overall activation (all trails) for experienced and inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the PFC asymmetry are given. This table is related to Figures C.7 to C.10.

PFC Asymmetry		Round 1 - Exp				Round 1 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	0.269	0.034	0.236	0.337	-0.462	0.032	-0.506	-0.407
	O2Hb	0.048	0.075	-0.136	0.122	0.205	0.073	0.129	0.341
Ch5-Ch10	HHb	0.080	0.005	0.070	0.088	0.242	0.026	0.165	0.265
	O2Hb	0.697	0.115	0.446	0.821	-0.436	0.088	-0.527	-0.287
Ch5-12	HHb	0.217	0.043	0.010	0.360	0.293	0.046	0.190	0.340
	O2Hb	1.165	0.015	1.119	1.192	0.003	0.032	-0.101	0.035
Ch6-Ch 9	HHb	-0.046	0.040	-0.091	0.042	-0.238	0.014	-0.266	-0.223
	O2Hb	-1.355	0.074	-1.470	-1.169	-0.201	0.036	-0.242	-0.122
Ch6-Ch10	HHb	-0.249	0.023	-0.281	-0.217	0.231	0.017	0.192	0.257
	O2Hb	-0.118	0.116	-0.329	0.023	0.296	0.050	0.237	0.395
Ch6-Ch12	HHb	-0.030	0.102	-0.200	0.135	-0.065	0.032	-0.143	-0.020
	O2Hb	-0.280	0.049	-0.340	-0.179	0.643	0.067	0.570	0.746
Ch7-Ch 9	HHb	0.012	0.040	-0.031	0.085	-0.174	0.132	-0.352	-0.018
	O2Hb	-1.311	0.047	-1.448	-1.241	-0.326	0.131	-0.510	-0.176
Ch7-Ch10	HHb	0.223	0.033	0.180	0.282	-0.096	0.023	-0.136	-0.066
	O2Hb	-0.807	0.050	-0.932	-0.761	-0.525	0.068	-0.644	-0.429
Ch7-Ch12	HHb	-0.195	0.027	-0.237	-0.133	0.068	0.086	-0.054	0.176
	O2Hb	0.306	0.044	0.221	0.375	0.190	0.193	-0.123	0.408
Ch8-Ch 9	HHb	-0.159	0.045	-0.209	-0.076	-0.107	0.049	-0.168	-0.032
	O2Hb	-0.664	0.067	-0.815	-0.589	0.021	0.031	-0.029	0.069
Ch8-Ch10	HHb	-0.033	0.007	-0.044	-0.016	-0.370	0.064	-0.519	-0.300
	O2Hb	0.249	0.041	0.189	0.309	-0.036	0.047	-0.124	0.026
Ch8-Ch12	HHb	-0.365	0.044	-0.426	-0.302	0.021	0.066	-0.082	0.101
	O2Hb	0.600	0.039	0.535	0.662	-0.169	0.106	-0.314	-0.016

Table D.22: Results of the activation for experienced and inexperienced players during the first round. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the PFC asymmetry are given. This table is related to Figures C.7 to C.10.

PFC Asymmetry		Round 2 - Exp				Round 2 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.076	0.009	-0.085	-0.050	0.289	0.039	0.244	0.356
	O2Hb	0.011	0.090	-0.113	0.049	-0.606	0.036	-0.651	-0.539
Ch5-Ch10	HHb	-0.109	0.012	-0.138	-0.085	-0.313	0.018	-0.357	-0.289
	O2Hb	-0.066	0.041	-0.195	-0.003	0.084	0.039	-0.040	0.125
Ch5-12	HHb	0.015	0.030	-0.039	0.047	0.544	0.012	0.507	0.571
	O2Hb	-0.047	0.055	-0.176	0.000	-0.304	0.090	-0.399	-0.098
Ch6-Ch 9	HHb	-0.302	0.054	-0.380	-0.236	-0.233	0.063	-0.316	-0.129
	O2Hb	0.595	0.075	0.486	0.733	-0.575	0.081	-0.699	-0.473
Ch6-Ch10	HHb	-0.600	0.044	-0.694	-0.552	0.088	0.043	0.018	0.136
	O2Hb	0.432	0.044	0.316	0.489	0.312	0.052	0.219	0.380
Ch6-Ch12	HHb	-0.198	0.055	-0.278	-0.136	0.644	0.026	0.578	0.684
	O2Hb	0.529	0.026	0.478	0.564	1.484	0.055	1.313	1.539
Ch7-Ch 9	HHb	-0.578	0.074	-0.688	-0.474	1.433	0.367	0.805	1.860
	O2Hb	-0.315	0.028	-0.364	-0.249	-1.907	0.360	-2.339	-1.335
Ch7-Ch10	HHb	-0.293	0.047	-0.390	-0.163	-0.046	0.054	-0.158	0.079
	O2Hb	-0.290	0.052	-0.354	-0.124	0.139	0.049	0.037	0.203
Ch7-Ch12	HHb	0.064	0.063	-0.088	0.134	0.632	0.102	0.482	0.853
	O2Hb	0.173	0.029	0.102	0.215	0.317	0.099	0.156	0.503
Ch8-Ch 9	HHb	0.259	0.057	0.147	0.316	-0.075	0.083	-0.179	0.050
	O2Hb	-0.360	0.043	-0.434	-0.307	-0.321	0.061	-0.377	-0.140
Ch8-Ch10	HHb	-0.100	0.021	-0.146	-0.067	-0.123	0.034	-0.175	-0.081
	O2Hb	-0.573	0.073	-0.752	-0.475	0.068	0.082	-0.056	0.153
Ch8-Ch12	HHb	-0.248	0.069	-0.341	-0.163	0.226	0.047	0.151	0.288
	O2Hb	-0.010	0.042	-0.068	0.054	1.096	0.051	1.025	1.174

Table D.23: Results of the activation for experienced and inexperienced players during the second round. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the PFC asymmetry are given. This table is related to Figures C.7 to C.10.

PFC Asymmetry		Round 3 - Exp				Round 3 - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.132	0.024	-0.182	-0.110	0.090	0.047	0.031	0.193
	O2Hb	0.976	0.098	0.838	1.094	0.593	0.068	0.453	0.665
Ch5-Ch10	HHb	0.007	0.008	-0.007	0.017	-0.103	0.026	-0.133	-0.060
	O2Hb	0.684	0.096	0.499	0.787	0.564	0.064	0.444	0.663
Ch5-12	HHb	-0.521	0.026	-0.575	-0.497	1.590	0.033	1.553	1.644
	O2Hb	-0.164	0.094	-0.309	-0.015	0.586	0.056	0.524	0.669
Ch6-Ch 9	HHb	-0.054	0.025	-0.088	0.000	0.996	0.028	0.959	1.040
	O2Hb	0.249	0.121	0.085	0.467	1.292	0.039	1.202	1.342
Ch6-Ch10	HHb	-0.143	0.046	-0.268	-0.105	1.408	0.028	1.369	1.470
	O2Hb	-0.551	0.110	-0.664	-0.290	0.863	0.209	0.408	1.069
Ch6-Ch12	HHb	-0.229	0.017	-0.266	-0.209	1.393	0.032	1.317	1.431
	O2Hb	-1.359	0.086	-1.457	-1.234	0.694	0.132	0.511	0.881
Ch7-Ch 9	HHb	-0.357	0.057	-0.431	-0.272	0.142	0.039	0.093	0.209
	O2Hb	-0.462	0.038	-0.524	-0.362	1.479	0.060	1.383	1.566
Ch7-Ch10	HHb	-0.599	0.006	-0.613	-0.592	0.123	0.029	0.087	0.173
	O2Hb	-0.260	0.067	-0.384	-0.183	0.955	0.120	0.671	1.067
Ch7-Ch12	HHb	-0.963	0.043	-1.026	-0.893	1.562	0.089	1.424	1.706
	O2Hb	-1.210	0.040	-1.283	-1.163	0.833	0.078	0.668	0.961
Ch8-Ch 9	HHb	-0.355	0.050	-0.443	-0.272	-0.077	0.014	-0.099	-0.046
	O2Hb	0.332	0.039	0.291	0.422	0.397	0.058	0.343	0.523
Ch8-Ch10	HHb	-0.634	0.015	-0.660	-0.610	-0.629	0.056	-0.705	-0.553
	O2Hb	0.886	0.029	0.833	0.931	0.268	0.140	0.089	0.477
Ch8-Ch12	HHb	-0.419	0.018	-0.453	-0.400	0.664	0.054	0.534	0.721
	O2Hb	-0.475	0.048	-0.578	-0.387	0.741	0.021	0.717	0.772

Table D.24: Results of the activation for experienced and inexperienced players during the third round. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the PFC asymmetry are given. This table is related to Figures C.7 to C.10.

D.4 Anxiety vs No Anxiety

Motor Cortex

Motor Cortex		Anxious - Overall				Not Anxious - Overall			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	-0.526	0.028	-0.584	-0.477	-0.419	0.124	-0.631	-0.251
	O2Hb	-0.911	0.093	-1.062	-0.796	0.173	0.078	0.087	0.312
Ch2	HHb	-1.191	0.077	-1.317	-1.079	0.176	0.062	0.043	0.257
	O2Hb	-0.126	0.116	-0.266	0.023	0.283	0.038	0.220	0.341
Ch3	HHb	0.139	0.066	0.024	0.243	-0.297	0.045	-0.355	-0.225
	O2Hb	0.171	0.094	0.036	0.285	-0.002	0.036	-0.039	0.077

Table D.25: Results of the overall activation (both experienced and inexperienced) for anxious and not anxious players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.11.

Motor Cortex		Anxious - Exp				Not Anxious - Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	1.601	0.101	1.324	1.751	-0.752	0.068	-0.879	-0.647
	O2Hb	-0.768	0.187	-1.079	-0.483	0.334	0.091	0.228	0.514
Ch2	HHb	-1.005	0.329	-1.418	-0.496	0.366	0.049	0.253	0.420
	O2Hb	0.115	0.309	-0.481	0.421	0.053	0.050	-0.008	0.148
Ch3	HHb	-0.076	0.016	-0.102	-0.051	-0.254	0.032	-0.292	-0.176
	O2Hb	-0.803	0.096	-0.918	-0.579	-0.285	0.025	-0.321	-0.238

Table D.26: Results of the activation for anxious and not anxious experienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.11.

Motor Cortex		Anxious - Non-Exp				Not Anxious - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	-0.982	0.022	-1.016	-0.948	0.192	0.344	-0.205	0.713
	O2Hb	-0.943	0.075	-1.059	-0.841	-0.085	0.272	-0.376	0.335
Ch2	HHb	-1.290	0.151	-1.615	-1.097	-0.186	0.112	-0.356	0.023
	O2Hb	-0.216	0.109	-0.388	-0.058	0.675	0.043	0.599	0.732
Ch3	HHb	0.233	0.094	0.073	0.379	-0.376	0.083	-0.481	-0.219
	O2Hb	0.607	0.103	0.458	0.755	0.522	0.095	0.353	0.665

Table D.27: Results of the activation for anxious and not anxious inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.11.

Left Temporal Cortex

Left Temp Cortex		Anxious - Overall				Not Anxious - Overall			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	-0.063	0.018	-0.084	-0.027	-0.112	0.008	-0.124	-0.098
	O2Hb	-0.126	0.009	-0.144	-0.112	-0.136	0.043	-0.190	-0.062
Ch14	HHb	0.089	0.092	-0.138	0.220	0.056	0.063	-0.012	0.188
	O2Hb	0.513	0.125	0.373	0.757	0.470	0.060	0.389	0.550
Ch15	HHb	0.287	0.019	0.255	0.305	0.054	0.007	0.046	0.067
	O2Hb	0.015	0.017	-0.070	0.072	-0.252	0.015	-0.275	-0.229
Ch16	HHb	0.313	0.135	0.136	0.513	0.459	0.047	0.396	0.532
	O2Hb	0.028	0.061	-0.117	0.163	0.269	0.027	0.226	0.316

Table D.28: Results of the overall activation (both experienced and inexperienced) for anxious and not anxious players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.12.

Left Temp Cortex		Anxious - Exp				Not Anxious - Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	-0.304	0.025	-0.330	-0.285	0.002	0.017	-0.020	0.035
	O2Hb	-0.037	0.023	-0.065	-0.002	-0.223	0.045	-0.278	-0.132
Ch14	HHb	-0.186	0.090	-0.414	-0.038	0.011	0.026	-0.019	0.072
	O2Hb	0.086	0.126	-0.081	0.265	0.341	0.042	0.294	0.422
Ch15	HHb	-0.240	0.026	-0.285	-0.209	0.064	0.009	0.055	0.085
	O2Hb	0.194	0.039	0.146	0.288	-0.344	0.024	-0.381	-0.306
Ch16	HHb	0.182	0.014	0.163	0.218	0.345	0.044	0.299	0.438
	O2Hb	0.266	0.070	0.173	0.354	0.193	0.034	0.158	0.253

Table D.29: Results of the activation for anxious and not anxious experienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.12.

Left Temp Cortex		Anxious - Non-Exp				Not Anxious - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	0.078	0.014	0.059	0.111	-0.281	0.012	-0.311	-0.259
	O2Hb	-0.173	0.024	-0.212	-0.143	0.070	0.043	0.047	0.077
Ch14	HHb	0.166	0.102	-0.061	0.320	0.137	0.135	-0.027	0.395
	O2Hb	0.610	0.133	0.458	0.877	0.665	0.098	0.528	0.808
Ch15	HHb	0.457	0.030	0.410	0.489	0.011	0.017	-0.023	0.033
	O2Hb	-0.044	0.027	-0.106	0.014	0.211	0.051	0.140	0.294
Ch16	HHb	0.348	0.173	0.119	0.602	0.822	0.103	0.637	0.981
	O2Hb	-0.045	0.071	-0.225	0.109	0.483	0.146	0.150	0.643

Table D.30: Results of the activation for anxious and not anxious inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.12.

Total PFC

Total PFC		Anxious - Overall				Not Anxious - Overall			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.036	0.005	-0.048	-0.029	0.048	0.005	0.034	0.055
	O2Hb	-0.005	0.015	-0.020	0.033	-0.299	0.020	-0.324	-0.269
Ch5-Ch10	HHb	-0.032	0.006	-0.041	-0.016	0.048	0.008	0.041	0.067
	O2Hb	-0.252	0.029	-0.281	-0.191	-0.084	0.012	-0.099	-0.050
Ch5-12	HHb	-0.297	0.002	-0.300	-0.291	0.014	0.006	0.006	0.030
	O2Hb	-0.197	0.010	-0.215	-0.171	-0.012	0.025	-0.042	0.036
Ch6-Ch 9	HHb	0.062	0.008	0.050	0.073	0.030	0.010	0.003	0.038
	O2Hb	-0.083	0.054	-0.151	-0.010	-0.033	0.015	-0.054	0.002
Ch6-Ch10	HHb	-0.031	0.011	-0.047	-0.016	0.166	0.006	0.155	0.176
	O2Hb	-0.256	0.077	-0.336	-0.097	-0.234	0.042	-0.275	-0.127
Ch6-Ch12	HHb	-0.285	0.026	-0.336	-0.233	0.044	0.008	0.032	0.065
	O2Hb	-0.451	0.058	-0.528	-0.357	-0.164	0.058	-0.223	-0.018
Ch7-Ch 9	HHb	0.081	0.031	0.028	0.119	0.000	0.017	-0.019	0.029
	O2Hb	-0.042	0.016	-0.062	-0.017	-0.468	0.021	-0.524	-0.438
Ch7-Ch10	HHb	-0.019	0.014	-0.038	0.010	0.032	0.015	0.012	0.057
	O2Hb	-0.255	0.054	-0.323	-0.163	-0.232	0.023	-0.261	-0.178
Ch7-Ch12	HHb	-0.248	0.024	-0.286	-0.216	0.135	0.010	0.120	0.149
	O2Hb	-0.679	0.040	-0.740	-0.599	-0.294	0.018	-0.316	-0.252
Ch8-Ch 9	HHb	0.016	0.024	-0.036	0.051	0.079	0.016	0.046	0.095
	O2Hb	0.101	0.059	0.037	0.220	-0.410	0.034	-0.450	-0.359
Ch8-Ch10	HHb	-0.067	0.015	-0.082	-0.034	0.072	0.008	0.060	0.084
	O2Hb	-0.162	0.038	-0.194	-0.064	-0.483	0.047	-0.536	-0.396
Ch8-Ch12	HHb	-0.190	0.020	-0.212	-0.146	-0.069	0.014	-0.081	-0.030
	O2Hb	-0.357	0.015	-0.381	-0.340	-0.238	0.027	-0.282	-0.188

Table D.31: Results of the overall activation (both experienced and inexperienced) for anxious and not anxious players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.13 to C.16.

Total PFC		Anxious - Exp				Not Anxious - Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.207	0.004	-0.214	-0.201	0.088	0.003	0.079	0.091
	O2Hb	0.236	0.018	0.214	0.277	-0.360	0.014	-0.377	-0.330
Ch5-Ch10	HHb	-0.024	0.007	-0.035	-0.015	0.016	0.004	0.011	0.025
	O2Hb	-0.449	0.076	-0.526	-0.302	-0.137	0.019	-0.159	-0.088
Ch5-12	HHb	0.015	0.011	-0.002	0.026	0.037	0.009	0.027	0.056
	O2Hb	-0.212	0.017	-0.248	-0.160	-0.095	0.031	-0.130	-0.029
Ch6-Ch 9	HHb	-0.222	0.029	-0.254	-0.160	-0.095	0.007	-0.105	-0.086
	O2Hb	-0.115	0.104	-0.250	0.046	-0.028	0.036	-0.061	0.076
Ch6-Ch10	HHb	-0.186	0.022	-0.218	-0.130	0.142	0.017	0.117	0.162
	O2Hb	-0.671	0.096	-0.771	-0.469	-0.258	0.056	-0.318	-0.114
Ch6-Ch12	HHb	-0.050	0.053	-0.116	0.058	0.038	0.007	0.029	0.060
	O2Hb	-0.524	0.069	-0.629	-0.419	-0.055	0.055	-0.113	0.086
Ch7-Ch 9	HHb	-0.427	0.018	-0.453	-0.397	-0.085	0.008	-0.094	-0.063
	O2Hb	-0.375	0.037	-0.434	-0.328	-0.570	0.071	-0.693	-0.457
Ch7-Ch10	HHb	-0.106	0.036	-0.156	-0.063	-0.022	0.018	-0.041	0.029
	O2Hb	-0.918	0.073	-1.015	-0.816	-0.396	0.044	-0.449	-0.303
Ch7-Ch12	HHb	-0.070	0.028	-0.097	0.005	0.130	0.010	0.114	0.142
	O2Hb	-0.711	0.023	-0.757	-0.679	-0.362	0.024	-0.390	-0.315
Ch8-Ch 9	HHb	-0.156	0.020	-0.191	-0.119	0.114	0.024	0.069	0.144
	O2Hb	0.075	0.041	0.032	0.171	-0.520	0.028	-0.558	-0.472
Ch8-Ch10	HHb	0.056	0.005	0.044	0.066	0.044	0.007	0.031	0.053
	O2Hb	-0.288	0.027	-0.315	-0.209	-0.556	0.065	-0.621	-0.419
Ch8-Ch12	HHb	0.107	0.009	0.094	0.121	-0.026	0.014	-0.039	0.011
	O2Hb	-0.467	0.021	-0.512	-0.441	-0.339	0.046	-0.388	-0.247

Table D.32: Results of the activation for anxious and not anxious experienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.13 to C.16.

Total PFC		Anxious - Non-Exp				Not Anxious - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	0.059	0.006	0.044	0.068	-0.120	0.016	-0.153	-0.099
	O2Hb	-0.138	0.024	-0.159	-0.088	-0.080	0.081	-0.246	-0.001
Ch5-Ch10	HHb	-0.036	0.010	-0.052	-0.016	0.166	0.024	0.141	0.215
	O2Hb	-0.171	0.012	-0.182	0.146	0.074	0.010	0.055	0.089
Ch5-12	HHb	-0.463	0.006	-0.469	-0.447	-0.092	0.016	-0.108	-0.063
	O2Hb	-0.189	0.008	-0.204	-0.177	0.340	0.020	0.310	0.371
Ch6-Ch 9	HHb	0.171	0.011	0.144	0.187	0.467	0.050	0.380	0.525
	O2Hb	-0.071	0.036	-0.121	-0.024	-0.050	0.078	-0.246	0.029
Ch6-Ch10	HHb	0.013	0.010	-0.004	0.025	0.236	0.037	0.170	0.278
	O2Hb	-0.091	0.070	-0.164	0.052	-0.168	0.020	-0.231	-0.151
Ch6-Ch12	HHb	-0.338	0.021	-0.385	-0.298	0.089	0.027	0.052	0.165
	O2Hb	-0.433	0.055	-0.504	-0.341	-0.929	0.091	-1.027	-0.745
Ch7-Ch 9	HHb	0.366	0.057	0.267	0.436	0.202	0.056	0.129	0.272
	O2Hb	0.108	0.017	0.081	0.129	-0.203	0.119	-0.389	-0.064
Ch7-Ch10	HHb	0.019	0.023	-0.020	0.049	0.150	0.055	0.082	0.247
	O2Hb	0.004	0.048	-0.055	0.096	0.182	0.040	0.128	0.239
Ch7-Ch12	HHb	-0.338	0.038	-0.388	-0.286	0.157	0.015	0.137	0.191
	O2Hb	-0.660	0.054	-0.732	-0.552	0.085	0.024	0.010	0.107
Ch8-Ch 9	HHb	0.159	0.030	0.093	0.194	-0.043	0.024	-0.103	-0.023
	O2Hb	0.123	0.074	0.040	0.261	-0.115	0.092	-0.273	-0.023
Ch8-Ch10	HHb	-0.119	0.021	-0.143	-0.077	0.179	0.032	0.099	0.206
	O2Hb	-0.103	0.044	-0.141	0.003	-0.294	0.020	-0.337	-0.265
Ch8-Ch12	HHb	-0.396	0.031	-0.442	-0.327	-0.261	0.017	-0.277	-0.220
	O2Hb	-0.272	0.021	-0.307	-0.244	0.078	0.040	-0.003	0.164

Table D.33: Results of the activation for anxious and not anxious inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.13 to C.16.

PFC Asymmetry

PFC Asymmetry		Anxious - Overall				Not Anxious - Overall			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	0.072	0.010	0.058	0.096	-0.096	0.011	-0.109	-0.068
	O2Hb	0.009	0.030	-0.066	0.039	0.597	0.041	0.538	0.648
Ch5-Ch10	HHb	0.064	0.012	0.032	0.081	-0.097	0.016	-0.133	-0.082
	O2Hb	0.503	0.059	0.383	0.562	0.168	0.025	0.100	0.198
Ch5-12	HHb	0.594	0.004	0.582	0.600	-0.029	0.013	-0.059	-0.013
	O2Hb	0.393	0.020	0.342	0.429	0.024	0.050	-0.071	0.083
Ch6-Ch 9	HHb	0.092	0.011	0.071	0.102	-0.014	0.011	-0.027	0.017
	O2Hb	0.387	0.035	0.320	0.434	0.051	0.039	0.008	0.146
Ch6-Ch10	HHb	0.213	0.027	0.166	0.253	-0.138	0.019	-0.173	-0.114
	O2Hb	0.265	0.072	0.105	0.355	0.058	0.029	0.025	0.113
Ch6-Ch12	HHb	0.721	0.011	0.694	0.737	-0.252	0.039	-0.325	-0.213
	O2Hb	0.941	0.041	0.885	1.006	-0.387	0.037	-0.435	-0.304
Ch7-Ch 9	HHb	0.207	0.079	0.055	0.292	-0.329	0.051	-0.392	-0.251
	O2Hb	-0.066	0.051	-0.147	0.003	-0.231	0.028	-0.271	-0.158
Ch7-Ch10	HHb	-0.104	0.017	-0.160	-0.084	-0.217	0.022	-0.249	-0.155
	O2Hb	0.135	0.079	-0.019	0.237	-0.281	0.023	-0.322	-0.211
Ch7-Ch12	HHb	0.271	0.043	0.151	0.329	-0.254	0.012	-0.267	-0.218
	O2Hb	0.073	0.078	-0.037	0.189	-0.186	0.021	-0.219	-0.160
Ch8-Ch 9	HHb	0.171	0.044	0.103	0.240	-0.212	0.042	-0.282	-0.143
	O2Hb	-0.266	0.018	-0.294	-0.243	0.052	0.010	0.035	0.083
Ch8-Ch10	HHb	-0.263	0.067	-0.404	-0.201	-0.365	0.032	-0.409	-0.305
	O2Hb	0.108	0.057	0.001	0.180	0.103	0.044	0.041	0.172
Ch8-Ch12	HHb	0.132	0.055	-0.005	0.190	-0.309	0.012	-0.328	-0.278
	O2Hb	0.848	0.026	0.766	0.868	-0.307	0.008	-0.317	-0.288

Table D.34: Results of the overall activation (both experienced and inexperienced) for anxious and not anxious players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the PFC asymmetry are given. This table is related to Figures C.17 to C.20.

PFC Asymmetry		Anxious - Exp Mean	Std	Min	Max	Not Anxious - Exp Mean	Std	Min	Max
Ch5-Ch9	HHb	0.415	0.009	0.401	0.427	-0.177	0.006	-0.183	-0.158
	O2Hb	-0.472	0.036	-0.554	-0.428	0.719	0.027	0.660	0.755
Ch5-Ch10	HHb	0.047	0.014	0.031	0.070	-0.032	0.008	-0.051	-0.022
	O2Hb	0.897	0.152	0.603	1.052	0.273	0.038	0.177	0.318
Ch5-12	HHb	-0.029	0.022	-0.051	0.004	-0.074	0.018	-0.112	-0.054
	O2Hb	0.423	0.035	0.320	0.495	0.190	0.063	0.058	0.260
Ch6-Ch 9	HHb	-0.073	0.112	-0.234	0.076	-0.178	0.014	-0.199	-0.154
	O2Hb	0.228	0.046	0.123	0.292	0.026	0.043	-0.019	0.133
Ch6-Ch10	HHb	-0.583	0.098	-0.779	-0.458	-0.324	0.018	-0.376	-0.302
	O2Hb	-0.103	0.082	-0.256	0.005	-0.100	0.041	-0.138	-0.015
Ch6-Ch12	HHb	-0.026	0.044	-0.094	0.037	-0.208	0.047	-0.285	-0.162
	O2Hb	0.745	0.105	0.529	0.867	-0.598	0.057	-0.655	-0.474
Ch7-Ch 9	HHb	-0.082	0.047	-0.164	-0.022	-0.441	0.027	-0.468	-0.384
	O2Hb	-1.413	0.067	-1.526	-1.331	-0.326	0.042	-0.362	-0.202
Ch7-Ch10	HHb	-0.733	0.041	-0.831	-0.694	-0.212	0.028	-0.253	-0.162
	O2Hb	-0.575	0.157	-0.913	-0.426	-0.385	0.021	-0.429	-0.318
Ch7-Ch12	HHb	-0.761	0.065	-0.848	-0.662	-0.372	0.036	-0.427	-0.297
	O2Hb	-0.187	0.147	-0.411	-0.013	-0.348	0.032	-0.419	-0.314
Ch8-Ch 9	HHb	0.365	0.053	0.265	0.431	-0.206	0.061	-0.313	-0.112
	O2Hb	-0.650	0.035	-0.715	-0.601	0.030	0.016	0.006	0.056
Ch8-Ch10	HHb	-0.070	0.078	-0.231	0.010	-0.358	0.031	-0.398	-0.295
	O2Hb	0.234	0.087	0.035	0.336	0.080	0.046	-0.003	0.153
Ch8-Ch12	HHb	-0.238	0.065	-0.409	-0.169	-0.370	0.027	-0.410	-0.316
	O2Hb	0.559	0.098	0.427	0.685	-0.255	0.011	-0.276	-0.240

Table D.35: Results of the activation for anxious and not anxious experienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the PFC asymmetry are given. This table is related to Figures C.17 to C.20.

PFC Asymmetry		Anxious - Non-Exp Mean	Std	Min	Max	Not Anxious - Non-Exp Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.119	0.013	-0.136	-0.089	0.239	0.032	0.199	0.306
	O2Hb	0.277	0.047	0.176	0.317	0.161	0.161	0.003	0.493
Ch5-Ch10	HHb	0.073	0.021	0.031	0.104	-0.332	0.047	-0.431	-0.281
	O2Hb	0.341	0.023	0.292	0.365	-0.148	0.020	-0.177	-0.110
Ch5-12	HHb	0.927	0.012	0.895	0.939	0.185	0.032	0.126	0.217
	O2Hb	0.378	0.017	0.354	0.408	-0.680	0.039	-0.743	-0.621
Ch6-Ch 9	HHb	0.156	0.028	0.112	0.197	0.558	0.033	0.511	0.613
	O2Hb	0.449	0.033	0.396	0.492	0.133	0.026	0.093	0.191
Ch6-Ch10	HHb	0.441	0.020	0.388	0.480	0.399	0.049	0.298	0.455
	O2Hb	0.413	0.076	0.216	0.496	0.497	0.018	0.471	0.540
Ch6-Ch12	HHb	0.887	0.009	0.860	0.898	-0.557	0.063	-0.696	-0.465
	O2Hb	0.990	0.031	0.944	1.046	1.090	0.153	0.883	1.367
Ch7-Ch 9	HHb	0.370	0.099	0.169	0.486	-0.064	0.113	-0.212	0.078
	O2Hb	0.540	0.084	0.414	0.642	0.018	0.115	-0.135	0.168
Ch7-Ch10	HHb	0.165	0.023	0.128	0.203	-0.226	0.034	-0.287	-0.140
	O2Hb	0.413	0.095	0.170	0.508	-0.019	0.032	-0.061	0.060
Ch7-Ch12	HHb	0.788	0.068	0.628	0.914	0.320	0.136	0.156	0.549
	O2Hb	0.226	0.048	0.141	0.308	0.724	0.298	0.320	1.124
Ch8-Ch 9	HHb	0.009	0.043	-0.034	0.080	-0.235	0.026	-0.274	-0.174
	O2Hb	0.059	0.048	0.006	0.133	0.111	0.048	0.063	0.271
Ch8-Ch10	HHb	-0.345	0.063	-0.479	-0.267	-0.393	0.036	-0.454	-0.342
	O2Hb	0.050	0.071	-0.093	0.120	0.161	0.043	0.092	0.222
Ch8-Ch12	HHb	0.389	0.054	0.275	0.444	-0.028	0.062	-0.109	0.050
	O2Hb	1.069	0.100	0.894	1.200	-0.468	0.058	-0.528	-0.328

Table D.36: Results of the activation for anxious and not anxious inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the PFC asymmetry are given. This table is related to Figures C.17 to C.20.

D.5 Goal vs No Goal

Motor Cortex

Motor Cortex		Goal - Overall				No Goal - Overall			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	-0.404	0.047	-0.481	-0.339	-0.566	0.122	-0.850	-0.398
	O2Hb	-0.197	0.062	-0.258	-0.071	-0.462	0.116	-0.648	-0.319
Ch2	HHb	-0.356	0.091	-0.471	-0.233	-0.403	0.044	-0.500	-0.344
	O2Hb	0.254	0.093	0.117	0.366	-0.126	0.043	-0.196	-0.048
Ch3	HHb	-0.024	0.037	-0.057	0.058	-0.191	0.080	-0.394	-0.120
	O2Hb	0.125	0.047	0.057	0.201	-0.005	0.101	-0.142	0.158

Table D.37: Results of the overall activation (both experienced and inexperienced) for scored and missed penalties. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.21.

Motor Cortex		Goal - Exp				No Goal - Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	-0.276	0.075	-0.416	-0.199	-0.158	0.209	-0.438	0.176
	O2Hb	0.458	0.065	0.380	0.587	-1.114	0.220	-1.371	-0.658
Ch2	HHb	0.169	0.102	0.153	0.610	0.452	0.147	0.153	0.610
	O2Hb	0.286	0.112	0.090	0.387	-0.682	0.085	-0.761	-0.515
Ch3	HHb	-0.193	0.029	-0.227	-0.139	-0.227	0.028	-0.289	-0.194
	O2Hb	-0.342	0.055	-0.411	-0.213	-0.901	0.039	-0.950	-0.802

Table D.38: Results of the activation for scored and missed penalties by experienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.21.

Motor Cortex		Goal - Non-Exp				No Goal - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch1	HHb	-0.559	0.052	-0.630	-0.453	-0.689	0.191	-0.991	-0.415
	O2Hb	-0.993	0.135	-1.162	-0.769	-0.266	0.122	-0.454	-0.077
Ch2	HHb	-0.640	0.107	-0.852	-0.501	-0.998	0.120	-1.232	-0.866
	O2Hb	0.208	0.083	0.110	0.364	0.121	0.050	0.040	0.264
Ch3	HHb	0.247	0.077	0.117	0.375	-0.179	0.112	-0.463	-0.066
	O2Hb	0.841	0.054	0.774	0.968	0.304	0.126	0.123	0.509

Table D.39: Results of the activation for scored and missed penalties by inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the motor cortex are given. This table is related to Figure C.21.

Left Temporal Cortex

Left Temp Cortex		Goal - Overall				No Goal - Overall			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	-0.067	0.017	-0.083	-0.028	-0.118	0.003	-0.123	-0.113
	O2Hb	-0.242	0.030	-0.281	-0.204	0.010	0.032	-0.036	0.061
Ch14	HHb	0.020	0.040	-0.070	0.099	0.129	0.069	0.041	0.326
	O2Hb	1.043	0.070	0.964	1.159	-0.140	0.150	-0.327	0.087
Ch15	HHb	0.052	0.011	0.040	0.075	0.256	0.012	0.227	0.271
	O2Hb	-0.271	0.017	-0.287	-0.227	-0.005	0.016	-0.029	0.019
Ch16	HHb	0.461	0.049	0.348	0.530	0.290	0.057	0.205	0.374
	O2Hb	0.378	0.043	0.315	0.448	-0.130	0.094	-0.258	-0.004

Table D.40: Results of the overall activation (both experienced and inexperienced) for scored and missed penalties. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.22.

Left Temp Cortex		Goal - Exp				No Goal - Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	-0.028	0.015	-0.044	0.009	-0.264	0.016	-0.285	-0.227
	O2Hb	0.007	0.039	-0.041	0.072	-0.510	0.034	-0.557	-0.452
Ch14	HHb	-0.057	0.038	-0.099	0.028	0.049	0.041	-0.058	0.107
	O2Hb	0.599	0.068	0.530	0.714	-0.418	0.041	-0.480	-0.322
Ch15	HHb	0.039	0.012	0.026	0.069	-0.029	0.048	-0.117	0.044
	O2Hb	-0.379	0.020	-0.412	-0.333	-0.021	0.033	-0.057	0.038
Ch16	HHb	0.259	0.055	0.201	0.381	0.460	0.013	0.429	0.477
	O2Hb	0.425	0.063	0.338	0.503	-0.388	0.045	-0.439	-0.275

Table D.41: Results of the activation for scored and missed penalties by experienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.22.

Left Temp Cortex		Goal - Non-Exp				No Goal - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch13	HHb	-0.121	0.019	-0.138	-0.079	-0.032	0.012	-0.056	-0.013
	O2Hb	-0.605	0.037	-0.653	-0.549	0.315	0.036	0.262	0.376
Ch14	HHb	0.136	0.068	-0.026	0.220	0.166	0.091	0.069	0.429
	O2Hb	1.634	0.108	1.481	1.805	-0.035	0.196	-0.269	0.265
Ch15	HHb	0.088	0.009	0.072	0.100	0.478	0.031	0.409	0.506
	O2Hb	0.068	0.077	-0.062	0.157	0.007	0.011	-0.021	0.023
Ch16	HHb	0.802	0.198	0.534	1.080	0.211	0.077	0.099	0.325
	O2Hb	0.288	0.218	-0.024	0.594	-0.004	0.157	-0.235	0.199

Table D.42: Results of the activation for scored and missed penalties by inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel of the left temporal cortex are given. This table is related to Figure C.22.

Total PFC

Total PFC		Goal - Overall				No Goal - Overall			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	0.058	0.006	0.042	0.063	-0.046	0.010	-0.072	-0.029
	O2Hb	-0.094	0.010	-0.105	-0.066	-0.233	0.016	-0.251	-0.207
Ch5-Ch10	HHb	-0.016	0.004	-0.021	-0.009	0.060	0.005	0.054	0.072
	O2Hb	0.011	0.013	-0.001	0.051	-0.291	0.018	-0.313	-0.245
Ch5-Ch12	HHb	-0.124	0.008	-0.134	-0.110	-0.059	0.006	-0.070	-0.051
	O2Hb	-0.071	0.023	-0.092	-0.019	-0.089	0.013	-0.111	-0.069
Ch6-Ch9	HHb	-0.042	0.004	-0.055	-0.037	0.182	0.007	0.159	0.191
	O2Hb	0.172	0.035	0.142	0.267	-0.449	0.108	-0.593	-0.292
Ch6-Ch10	HHb	0.101	0.007	0.090	0.110	0.096	0.016	0.064	0.113
	O2Hb	-0.085	0.038	-0.130	-0.001	-0.479	0.022	-0.507	-0.428
Ch6-Ch12	HHb	-0.111	0.012	-0.126	-0.078	-0.025	0.015	-0.055	0.012
	O2Hb	-0.218	0.043	-0.261	-0.107	-0.475	0.089	-0.583	-0.334
Ch7-Ch9	HHb	0.003	0.015	-0.020	0.022	0.072	0.021	0.044	0.102
	O2Hb	-0.233	0.040	-0.312	-0.180	-0.333	0.030	-0.383	-0.300
Ch7-Ch10	HHb	0.032	0.024	-0.001	0.068	-0.009	0.016	-0.023	0.022
	O2Hb	-0.190	0.025	-0.222	-0.142	-0.305	0.021	-0.333	-0.264
Ch7-Ch12	HHb	-0.026	0.029	-0.065	0.017	0.031	0.016	0.002	0.053
	O2Hb	-0.393	0.016	-0.410	-0.357	-0.481	0.027	-0.517	-0.424
Ch8-Ch9	HHb	0.064	0.025	0.012	0.091	0.044	0.027	-0.009	0.089
	O2Hb	-0.186	0.027	-0.205	-0.109	-0.205	0.015	-0.223	-0.175
Ch8-Ch10	HHb	0.145	0.019	0.113	0.173	-0.105	0.041	-0.158	-0.033
	O2Hb	-0.375	0.020	-0.397	-0.328	-0.346	0.031	-0.383	-0.287
Ch8-Ch12	HHb	-0.102	0.018	-0.120	-0.065	-0.128	0.030	-0.160	-0.067
	O2Hb	-0.343	0.014	-0.358	-0.304	-0.200	0.040	-0.258	-0.157

Table D.43: Results of the overall activation (both experienced and inexperienced) for scored and missed penalties. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.23 to C.26.

Total PFC		Goal - Exp				No Goal - Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.002	0.005	-0.016	0.003	0.014	0.009	0.004	0.040
	O2Hb	-0.083	0.022	-0.110	-0.041	-0.395	0.007	-0.405	-0.385
Ch5-Ch10	HHb	-0.013	0.004	-0.019	-0.006	0.047	0.005	0.041	0.063
	O2Hb	-0.049	0.016	-0.067	-0.004	-0.421	0.036	-0.456	-0.324
Ch5-Ch12	HHb	-0.009	0.007	-0.018	0.006	0.114	0.004	0.107	0.121
	O2Hb	-0.099	0.033	-0.132	-0.031	-0.154	0.006	-0.164	-0.146
Ch6-Ch9	HHb	-0.206	0.005	-0.214	-0.199	0.117	0.020	0.092	0.148
	O2Hb	0.122	0.049	0.076	0.255	-0.574	0.125	-0.751	-0.424
Ch6-Ch10	HHb	0.142	0.013	0.122	0.156	-0.045	0.011	-0.065	-0.033
	O2Hb	-0.130	0.046	-0.182	-0.021	-1.051	0.067	-1.129	-0.923
Ch6-Ch12	HHb	-0.032	0.013	-0.049	0.001	0.345	0.009	0.335	0.373
	O2Hb	0.015	0.053	-0.040	0.154	-0.759	0.035	-0.808	-0.702
Ch7-Ch9	HHb	-0.220	0.005	-0.225	-0.204	-0.102	0.012	-0.110	-0.066
	O2Hb	-0.309	0.070	-0.420	-0.190	-0.836	0.026	-0.910	-0.809
Ch7-Ch10	HHb	0.028	0.019	0.000	0.077	-0.163	0.020	-0.186	-0.112
	O2Hb	-0.470	0.035	-0.511	-0.391	-0.518	0.036	-0.564	-0.437
Ch7-Ch12	HHb	0.061	0.014	0.038	0.081	0.157	0.011	0.143	0.187
	O2Hb	-0.295	0.030	-0.331	-0.235	-0.693	0.013	-0.721	-0.677
Ch8-Ch9	HHb	0.066	0.034	-0.011	0.101	0.011	0.018	-0.004	0.061
	O2Hb	-0.262	0.037	-0.312	-0.191	-0.440	0.033	-0.487	-0.387
Ch8-Ch10	HHb	0.198	0.032	0.134	0.237	-0.193	0.059	-0.253	-0.072
	O2Hb	-0.434	0.062	-0.495	-0.301	-0.613	0.030	-0.644	-0.554
Ch8-Ch12	HHb	0.016	0.025	-0.031	0.050	-0.017	0.038	-0.065	0.060
	O2Hb	-0.368	0.044	-0.413	-0.271	-0.380	0.029	-0.456	-0.353

Table D.44: Results of the activation for scored and missed penalties by experienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.23 to C.26.

Total PFC		Goal - Non-Exp				No Goal - Non-Exp			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	0.228	0.011	0.208	0.242	-0.092	0.013	-0.128	-0.080
	O2Hb	-0.128	0.036	-0.200	-0.089	-0.119	0.025	-0.145	-0.069
Ch5-Ch10	HHb	-0.026	0.008	-0.034	-0.004	0.071	0.006	0.062	0.081
	O2Hb	0.192	0.033	0.132	0.223	-0.187	0.012	-0.203	-0.161
Ch5-Ch12	HHb	-0.382	0.013	-0.398	-0.353	-0.302	0.009	-0.320	-0.291
	O2Hb	-0.010	0.009	-0.021	0.011	0.002	0.029	-0.055	0.046
Ch6-Ch9	HHb	0.304	0.013	0.275	0.325	0.228	0.024	0.168	0.251
	O2Hb	0.279	0.025	0.206	0.301	-0.374	0.098	-0.501	-0.210
Ch6-Ch10	HHb	-0.003	0.011	-0.019	0.011	0.167	0.027	0.116	0.196
	O2Hb	0.036	0.026	0.001	0.080	-0.213	0.045	-0.259	-0.134
Ch6-Ch12	HHb	-0.263	0.011	-0.276	-0.230	-0.256	0.024	-0.304	-0.214
	O2Hb	-0.667	0.032	-0.711	-0.611	-0.304	0.121	-0.453	-0.114
Ch7-Ch9	HHb	0.337	0.039	0.278	0.391	0.259	0.052	0.191	0.332
	O2Hb	-0.127	0.018	-0.166	-0.105	0.136	0.061	0.043	0.224
Ch7-Ch10	HHb	0.038	0.088	-0.062	0.170	0.109	0.015	0.092	0.135
	O2Hb	0.337	0.067	0.241	0.415	-0.131	0.028	-0.169	-0.083
Ch7-Ch12	HHb	-0.210	0.069	-0.297	-0.108	-0.152	0.029	-0.204	-0.123
	O2Hb	-0.636	0.027	-0.684	-0.602	-0.099	0.065	-0.178	0.031
Ch8-Ch9	HHb	0.060	0.008	0.048	0.072	0.093	0.052	-0.020	0.138
	O2Hb	-0.026	0.100	-0.216	0.095	0.069	0.068	-0.011	0.190
Ch8-Ch10	HHb	0.000	0.023	-0.026	0.054	-0.017	0.028	-0.080	0.009
	O2Hb	-0.238	0.096	-0.394	-0.094	-0.146	0.033	-0.188	-0.087
Ch8-Ch12	HHb	-0.369	0.025	-0.400	-0.316	-0.324	0.037	-0.410	-0.292
	O2Hb	-0.288	0.061	-0.380	0.177	0.030	0.060	-0.066	0.096

Table D.45: Results of the activation for scored and missed penalties by inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC activation are given. This table is related to Figures C.23 to C.26.

PFC Asymmetry

PFC Asymmetry		Goal - Overall				No Goal - Overall			
		Mean	Std	Min	Max	Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.115	0.011	-0.125	-0.083	0.093	0.020	0.058	0.143
	O2Hb	0.189	0.019	0.131	0.209	0.466	0.032	0.414	0.501
Ch5-Ch10	HHb	0.032	0.008	0.019	0.043	-0.120	0.010	-0.144	-0.107
	O2Hb	-0.023	0.026	-0.102	0.002	0.582	0.035	0.490	0.626
Ch5-Ch12	HHb	0.248	0.015	0.219	0.267	0.119	0.012	0.103	0.141
	O2Hb	0.142	0.045	0.038	0.183	0.178	0.025	0.138	0.222
Ch6-Ch9	HHb	-0.034	0.020	-0.051	0.016	0.131	0.029	0.079	0.176
	O2Hb	0.007	0.030	-0.026	0.084	0.506	0.047	0.428	0.570
Ch6-Ch10	HHb	-0.171	0.026	-0.236	-0.139	0.214	0.034	0.157	0.249
	O2Hb	-0.048	0.012	-0.073	-0.033	0.416	0.067	0.273	0.486
Ch6-Ch12	HHb	0.106	0.022	0.057	0.129	0.265	0.022	0.220	0.295
	O2Hb	0.255	0.035	0.210	0.309	0.042	0.075	-0.075	0.143
Ch7-Ch9	HHb	-0.150	0.046	-0.215	-0.095	-0.064	0.053	-0.145	-0.003
	O2Hb	-0.403	0.015	-0.417	-0.356	0.148	0.032	0.097	0.198
Ch7-Ch10	HHb	-0.320	0.045	-0.384	-0.252	0.006	0.057	-0.097	0.097
	O2Hb	-0.616	0.020	-0.651	-0.589	0.488	0.041	0.377	0.530
Ch7-Ch12	HHb	0.035	0.034	-0.016	0.083	-0.232	0.088	-0.354	-0.118
	O2Hb	-0.043	0.037	-0.097	0.010	-0.203	0.046	-0.267	-0.142
Ch8-Ch9	HHb	-0.105	0.036	-0.149	-0.040	-0.023	0.024	-0.065	0.000
	O2Hb	-0.111	0.012	-0.136	-0.095	-0.047	0.015	-0.061	0.006
Ch8-Ch10	HHb	-0.277	0.049	-0.383	-0.232	-0.387	0.051	-0.444	-0.289
	O2Hb	0.003	0.021	-0.037	0.021	0.214	0.062	0.088	0.274
Ch8-Ch12	HHb	-0.024	0.020	-0.072	-0.002	-0.332	0.040	-0.381	-0.241
	O2Hb	-0.148	0.048	-0.214	-0.067	0.532	0.053	0.456	0.595

Table D.46: Results of the overall activation (both experienced and inexperienced) for scored and missed penalties. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the total PFC asymmetry are given. This table is related to Figures C.27 to C.30.

PFC Asymmetry		Goal - Exp Mean	Std	Min	Max	No Goal - Exp Mean	Std	Min	Max
Ch5-Ch9	HHb	0.003	0.010	-0.006	0.032	-0.029	0.017	-0.080	-0.008
	O2Hb	0.165	0.044	0.081	0.220	0.789	0.014	0.770	0.810
Ch5-Ch10	HHb	0.026	0.009	0.012	0.037	-0.094	0.010	-0.125	-0.082
	O2Hb	0.098	0.032	0.008	0.134	0.842	0.073	0.647	0.912
Ch5-Ch12	HHb	0.019	0.014	-0.013	0.037	-0.228	0.009	-0.242	-0.214
	O2Hb	0.198	0.066	0.061	0.263	0.307	0.012	0.292	0.328
Ch6-Ch9	HHb	-0.151	0.022	-0.176	-0.096	-0.174	0.120	-0.358	0.003
	O2Hb	-0.137	0.049	-0.184	-0.019	0.713	0.039	0.664	0.777
Ch6-Ch10	HHb	-0.446	0.035	-0.524	-0.403	-0.070	0.059	-0.162	0.008
	O2Hb	-0.168	0.018	-0.199	-0.134	0.132	0.060	0.031	0.201
Ch6-Ch12	HHb	-0.111	0.039	-0.176	-0.072	-0.589	0.020	-0.625	-0.559
	O2Hb	-0.156	0.026	-0.188	-0.087	-1.469	0.086	-1.567	-1.348
Ch7-Ch9	HHb	-0.385	0.026	-0.407	-0.324	-0.293	0.026	-0.330	-0.251
	O2Hb	-0.616	0.057	-0.683	-0.484	-0.590	0.061	-0.685	-0.503
Ch7-Ch10	HHb	-0.433	0.032	-0.480	-0.383	-0.092	0.048	-0.185	0.018
	O2Hb	-0.841	0.016	-0.869	-0.819	0.381	0.121	0.096	0.611
Ch7-Ch12	HHb	-0.275	0.026	-0.329	-0.223	-0.784	0.051	-0.867	-0.729
	O2Hb	-0.340	0.059	-0.458	-0.254	-0.274	0.122	-0.460	-0.146
Ch8-Ch9	HHb	-0.087	0.071	-0.191	0.025	-0.012	0.030	-0.067	0.024
	O2Hb	-0.230	0.023	-0.277	-0.203	-0.115	0.018	-0.140	-0.088
Ch8-Ch10	HHb	-0.195	0.079	-0.364	-0.116	-0.490	0.089	-0.578	-0.301
	O2Hb	-0.019	0.019	-0.045	0.016	0.342	0.164	-0.011	0.495
Ch8-Ch12	HHb	-0.038	0.042	-0.138	0.001	-0.815	0.037	-0.841	-0.699
	O2Hb	-0.219	0.030	-0.266	-0.166	0.266	0.107	0.089	0.385

Table D.47: Results of the activation for scored and missed penalties by experienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the PFC asymmetry are given. This table is related to Figures C.27 to C.30.

PFC Asymmetry		Goal - Non-Exp Mean	Std	Min	Max	No Goal - Non-Exp Mean	Std	Min	Max
Ch5-Ch9	HHb	-0.457	0.021	-0.483	-0.415	0.184	0.027	0.161	0.257
	O2Hb	0.257	0.071	0.177	0.400	0.238	0.050	0.139	0.290
Ch5-Ch10	HHb	0.052	0.016	0.008	0.067	-0.143	0.012	-0.161	-0.124
	O2Hb	-0.385	0.066	-0.445	-0.263	0.375	0.024	0.323	0.406
Ch5-Ch12	HHb	0.763	0.027	0.707	0.795	0.604	0.017	0.583	0.640
	O2Hb	0.020	0.019	-0.023	0.042	-0.004	0.059	-0.092	0.111
Ch6-Ch9	HHb	0.213	0.021	0.180	0.252	0.345	0.038	0.290	0.397
	O2Hb	0.312	0.023	0.289	0.367	0.383	0.057	0.278	0.454
Ch6-Ch10	HHb	0.532	0.016	0.499	0.557	0.355	0.024	0.314	0.386
	O2Hb	0.272	0.048	0.160	0.323	0.548	0.074	0.387	0.630
Ch6-Ch12	HHb	0.525	0.030	0.461	0.565	0.799	0.023	0.748	0.829
	O2Hb	1.048	0.119	0.906	1.210	0.948	0.072	0.806	1.038
Ch7-Ch9	HHb	0.203	0.095	0.048	0.320	0.182	0.101	0.054	0.319
	O2Hb	-0.106	0.062	-0.177	-0.017	0.837	0.098	0.681	0.955
Ch7-Ch10	HHb	-0.120	0.071	-0.216	-0.018	0.080	0.067	-0.030	0.164
	O2Hb	-0.193	0.042	-0.293	-0.154	0.575	0.066	0.436	0.642
Ch7-Ch12	HHb	0.697	0.132	0.534	0.880	0.572	0.149	0.361	0.796
	O2Hb	0.692	0.241	0.337	0.969	-0.076	0.096	-0.187	0.094
Ch8-Ch9	HHb	-0.148	0.055	-0.206	-0.046	-0.040	0.019	-0.068	-0.002
	O2Hb	0.139	0.053	0.074	0.222	0.031	0.041	-0.006	0.159
Ch8-Ch10	HHb	-0.503	0.038	-0.586	-0.437	-0.283	0.025	-0.339	-0.260
	O2Hb	0.052	0.054	-0.073	0.116	0.118	0.020	0.088	0.163
Ch8-Ch12	HHb	0.009	0.050	-0.750	0.078	0.528	0.065	0.406	0.599
	O2Hb	0.009	0.089	-0.101	0.149	0.872	0.024	0.836	0.926

Table D.48: Results of the activation for scored and missed penalties by inexperienced players. Mean, standard deviation (std), the minimum values and the maximum values for each channel-pair regarding the PFC asymmetry are given. This table is related to Figures C.27 to C.30.

Bibliography

[1] Cork Gaines. *Why It's So Hard To Stop A Penalty Kick*. 2014. URL: https://www.businessinsider.com/penalty-kick-world-cup-2014-6?international=true&r=US&IR=T (visited on 03/09/2020).

[2] Shang-Ming Tsai. "An Analysis of Goalkeeper Diving Response Time For the Penalty Kick in Soccer". In: *International Symposium on Biomechanics in Sports*. Vol. 23. ISBS. Beijing, China, 2005, pp. 545–547.

[3] Kristine Dalton, Michel Guillon, and Shehzad A. Naroo. "An Analysis of Penalty Kicks in Elite Football Post 1997". In: *International Journal of Sports Science & Coaching* 10.5 (2015), pp. 815–827. DOI: 10.1260/1747-9541.10.5.815.

[4] Geir Jordet, Esther Hartman, Chris Visscher, and Koen A. P. M. Lemmink. "Kicks from the penalty mark in soccer: The roles of stress, skill, and fatigue for kick outcomes". In: *Journal of Sports Sciences* 25.2 (2007). PMID: 17127587, pp. 121–129. DOI: 10.1080/02640410600624020.

[5] Luc Arrondel, Richard Duhautois, and Jean-François Laslier. "Decision under psychological pressure: The shooter's anxiety at the penalty kick". In: *Journal of Economic Psychology* 70 (2019), pp. 22–35. ISSN: 0167-4870. DOI: 10.1016/j.joep.2018.10.008.

[6] Mark R. Wilson, Greg Wood, and Samuel J. Vine. "Anxiety, attentional control, and performance impairment in penalty kicks." In: *Journal of sport & exercise psychology* 31.6 (2009), pp. 761–75.

[7] Alex Korb. *Penalty Kicks and The Prefrontal Cortex*. July 2010. URL: https://www.psychologytoday.com/intl/blog/prefrontal-nudity/201007/penalty-kicks-and-the-prefrontal-cortex?amp (visited on 04/08/2020).

[8] T. Kuriyama, M. Asona, M. Nambu, and M. Yoshida. "Prefrontal Activity of Goal Keeping when Penalty Kick". In: *World Congress on Medical Physics and Biomedical Engineering*. Ed. by David A. Jaffray. Vol. 51. Cham, Switzerland: Springer, June 2015, pp. 1155–1158. DOI: 10.1007/978-3-319-19387-8_280.

[9] Daniel Carius, Lisa Hörnig, Patrick Ragert, and Elisabeth Kaminski. "Characterizing cortical hemodynamic changes during climbing and its relation to climbing expertise". In: *Neuroscience Letters* 715 (2020), p. 134604. ISSN: 0304-3940. DOI: 10.1016/j.neulet.2019.134604.

[10] Hiroyuki Ito, Hoshiko Yamauchi, Hitoshi Kaneko, Toru Yoshikawa, Kenji Nomura, and Shuji Honjo. "Prefrontal overactivation, autonomic arousal, and task performance under evaluative pressure: a near-infrared spectroscopy (NIRS) study". In: *Psychophysiology* 48.11 (Nov. 2011), pp. 1563–1571. ISSN: 0048-5772. DOI: 10.1111/j.1469-8986.2011.01220.x.

[11] Sebastian Wolf, Ellen Brölz, Philipp M. Keune, Benjamin Wesa, Martin Hautzinger, Niels Birbaumer, and Ute Strehl. "Motor skill failure or flow-experience? Functional brain asymmetry and brain connectivity in elite and amateur table tennis players". In: *Biological Psychology* 105 (2015), pp. 95–105. ISSN: 0301-0511. DOI: 10.1016/j.biopsycho.2015.01.007.

[12] Stefano I. Di Domenico, Achala H. Rodrigo, Mengxi Dong, Marc A. Fournier, Hasan Ayaz, Richard M. Ryan, and Anthony C. Ruocco. "Chapter 28 - Functional Near-Infrared Spectroscopy: Proof of Concept for Its Application in Social Neuroscience". In: *Neuroergonomics*. Ed. by Hasan Ayaz and Frédéric Dehais. Academic Press, 2019, pp. 169–173. ISBN: 978-0-12-811926-6. DOI: 10.1016/B978-0-12-811926-6.00028-2.

[13] Valentina Quaresima and Marco Ferrari. "Functional Near-Infrared Spectroscopy (fNIRS) for Assessing Cerebral Cortex Function During Human Behavior in Natural/Social Situations: A Concise Review". In: *Organizational Research Methods* 22.1 (2019), pp. 46–68. DOI: 10.1177/1094428116658959.

[14] Thomas C. Ferree, Matthew T. Clay, and Don M. Tucker. "The spatial resolution of scalp EEG". In: *Neurocomputing* 38-40 (2001). Computational Neuroscience: Trends in Research 2001, pp. 1209–1216. ISSN: 0925-2312. DOI: 10.1016/S0925-2312(01)00568-9.

[15] Kotaro Takeda, Shuntaro Okazaki, and Junichi Ushiyama. "Special Issues No.3 : Measurement Technique for Ergonomics, Section 4 : Measurements and Analyses of Bioelectric Phenomena and Others (3): Noninvasive Techniques for Measuring Brain Activity: EEG, fMRI, and fNIRS". In: *The Japanese journal of ergonomics* 51 (Dec. 2015), pp. 411–419. DOI: 10.5100/jje.51.411.

[16] Byung H. Kim and Sungho Jo. "Real-time motion artifact detection and removal for ambulatory BCI". In: *The 3rd International Winter Conference on Brain-Computer Interface*. IEEE, 2015. DOI: 10.1109/IWW-BCI.2015.7073050.

[17] Mikel Val-Calvo, José R. Álvarez-Sánchez, Jose M. Ferrández-Vicente, and Eduardo Fernández. "Optimization of Real-Time EEG Artifact Removal and Emotion Estimation for Human-Robot Interaction Applications". In: *Frontiers in Computational Neuroscience* 13 (2019). DOI: 10.3389/fncom.2019.00080.

[18] Wei-Long Zheng and Bao-Liang Lu. "Investigating Critical Frequency Bands and Channels for EEG-Based Emotion Recognition with Deep Neural Networks". In: *IEEE Transactions on Autonomous Mental Development* 7.3 (2015), pp. 162–175. DOI: 10.1109/TAMD.2015.2431497.

[19] Wei-Long Zheng, Jia-Yi Zhu, and Bao-Liang Lu. "Identifying Stable Patterns over Time for Emotion Recognition from EEG". In: *IEEE Transactions on Affective Computing* 10.3 (2019), pp. 417–429. DOI: 10.1109/TAFFC.2017.2712143.

[20] Charles D. Spielberger. "Manual for the State-Trait Anxiety Inventory (STAI)". In: Palo Alto, California: Consulting Psychologists Press, 1983.

[21] Brad Hatfield and Scott Kerick. "The psychology of superior sport performance: a cognitive and affective neuroscience perspective". In: *Handbook of sport psychology*. Ed. by Gerson Tenenbaum and Robert C. Eklund. Vol. 3. Hoboken, New Jersey: John Wiley & Sons Inc., Jan. 2007, pp. 84–109. DOI: https://doi.org/10.1002/9781118270011.ch4.

[22] Michael Bar-Eli and Ofer Azar. “Penalty kicks in soccer: An empirical analysis of shooting strategies and goalkeepers’ preferences”. In: *Soccer and Society* 10.2 (Mar. 2009), pp. 183–191. DOI: 10.1080/14660970802601654.

[23] Michael Bar-Eli, Ofer H. Azar, and Yotam Lurie. “(Ir)rationality in action: do soccer players and goalkeepers fail to learn how to best perform during a penalty kick?” In: *Progress in Brain Research*. Ed. by Markus Raab, Joseph G. Johnson, and Hauke R. Heekeren. Vol. 174. Amsterdam, Netherlands: Elsevier, Feb. 2009, pp. 97–108. DOI: 10.1016/S0079-6123(09)01309-0.

[24] Andrew H. Hunter, Michael J. Angilletta Jr, and Robbie S. Wilson. “Behaviors of shooter and goalkeeper interact to determine the outcome of soccer penalties”. In: *Scandinavian Journal of Medicine & Science in Sports* 28.12 (2018), pp. 2751–2759. DOI: 10.1111/sms.13276.

[25] Richard Masters, John van der Kamp, and Robin Jackson. “Imperceptibly Off-Center Goalkeepers Influence Penalty-Kick Direction in Soccer”. In: *Psychological science* 18 (Apr. 2007), pp. 222–3. DOI: 10.1111/j.1467-9280.2007.01878.x.

[26] Matthias Weigelt and Daniel Memmert. “Goal-Side Selection in Soccer Penalty Kicking When Viewing Natural Scenes”. In: *Frontiers in psychology* 3 (Sept. 2012), p. 312. DOI: 10.3389/fpsyg.2012.00312.

[27] Matthias Weigelt, Daniel Memmert, and Thomas Schack. “Kick it like Ballack: The effects of goalkeeping gestures on goal-side selection in experienced soccer players and soccer novices”. In: *Journal of Cognitive Psychology* 24 (Dec. 2012). DOI: 10.1080/20445911.2012.719494.

[28] Pierre Chiappori, Steven Levitt, and Timothy Groseclose. “Testing Mixed-Strategy Equilibria When Players Are Heterogeneous: The Case of Penalty Kicks in Soccer”. In: *American Economic Review* 92 (Sept. 2002), pp. 1138–1151. DOI: 10.1257/00028280260344678.

[29] Ignacio Palacios-Huerta. “Professionals Play Minimax”. In: *Review of Economic Studies* 70 (Feb. 2003), pp. 395–415. DOI: 10.1111/1467-937X.00249.

[30] Andrew M. Williams. “Perceptual Skill in Soccer: Implications for Talent Identification and Development”. In: *Journal of sports sciences* 18 (Oct. 2000), pp. 737–750. DOI: 10.1080/02640410050120113.

[31] Andrew M. Williams and Les Burwitz. “Advance cue utilization in soccer”. In: *Science and Football II*. Ed. by Thomas Reilly, Jan Clarys, and A. Stibbe. London, England: Taylor & Francis, 1993, pp. 239–243.

[32] Iain Greenlees, Michael Eynon, and Richard Thelwell. “Color of soccer goalkeepers’ uniforms influences the outcome of penalty kicks”. In: *Perceptual and motor skills* 117 (Aug. 2013), pp. 1043–52. DOI: 10.2466/30.24.PMS.116.3.

[33] Iain Greenlees, Alex Leyland, Richard Thelwell, and William Filby. “Soccer penalty takers’ uniform colour and pre-penalty kick gaze affect the impressions formed of them by opposing goalkeepers”. In: *Journal of Sports Sciences* 26.6 (2008). PMID: 18344127, pp. 569–576. DOI: 10.1080/02640410701744446.

[34] Martin J. Attrill, Karen A. Gresty, Russell A. Hill, and Robert A. Barton. “Red shirt colour is associated with long-term team success in English football”. In: *Journal of Sports Sciences* 26.6 (2008). PMID: 18344128, pp. 577–582. DOI: 10.1080/02640410701736244.

[35] Norbert Hagemann, Bernd Strauss, and Jan Leissing. “When the Referee Sees Red”. In: *Psychological science* 19 (Sept. 2008), pp. 769–71. DOI: 10.1111/j.1467-9280.2008.02155.x.

[36] Russell Hill and Robert Barton. “Psychology: Red enhances human performance in contests”. In: *Nature* 435 (June 2005), p. 293. DOI: 10.1038/435293a.

[37] Thomas J. Dohmen. “Do professionals choke under pressure?” In: *Journal of Economic Behavior & Organization* 65.3-4 (Jan. 2008), pp. 636–653. ISSN: 0167-2681. DOI: 10.1016/j.jebo.2005.12.004.

[38] Geir Jordet. “When Superstars Flop: Public Status and Choking Under Pressure in International Soccer Penalty Shootouts”. In: *Journal of Applied Sport Psychology* 21.2 (2009), pp. 125–130. DOI: 10.1080/10413200902777263.

[39] Geir Jordet. “Why do English players fail in soccer penalty shootouts? A study of team status, self-regulation, and choking under pressure”. In: *Journal of Sports Sciences* 27.2 (2009). PMID: 19058088, pp. 97–106. DOI: 10.1080/02640410802509144.

[40] Olaf Binsch, R.R.D. Oudejans, F.C. Bakker, M.J.M. Hoozemans, and R.A.H. Savelsberg. “Ironic effects in a penalty shooting task: Is the negative wording in the instruction essential?” In: *International Journal of Sport Psychology* 41 (2010), pp. 118–133. ISSN: 0047-0767.

[41] Olaf Binsch, Raôul R.D. Oudejans, Frank C. Bakker, and Geert J.P. Savelsbergh. “Ironic effects and final target fixation in a penalty shooting task”. In: *Human Movement Science* 29.2 (2010), pp. 277–288. ISSN: 0167-9457. DOI: 10.1016/j.humov.2009.12.002.

[42] Philip Furley, Matt Dicks, Fabian Stendtke, and Daniel Memmert. “”Get it out the way. The wait’s killing me.” hastening and hiding during soccer penalty kicks”. In: *Psychology of Sport and Exercise* 13.4 (2012), pp. 454–465. ISSN: 1469-0292. DOI: 10.1016/j.psychsport.2012.01.009.

[43] Greg Wood and Mark R. Wilson. “A moving goalkeeper distracts penalty takers and impairs shooting accuracy”. In: *Journal of Sports Sciences* 28.9 (2010). PMID: 20568032, pp. 937–946. DOI: 10.1080/02640414.2010.495995.

[44] Florian Loffing, Norbert Hagemann, and Toni Burmeister. “Zum Einfluss des Anlaufwinkels und des Schussfußes eines Schützen auf die Vorhersage der Ballflugrichtung beim Elfmeter [The influence of the run-up angle and kicking foot of a shooter on the prediction of ball direction during soccer penalties]”. In: *Psychophysiologie im Sport - zwishen Experiment und Handlungsoptimierung*. Ed. by G. Amesberger, T. Finkenzeller, and S. Würth. Cwalina. Hamburg, Germany: Feldhaus, 2010, S. 132.

[45] Matt Dicks, Keith Davids, and Chris Button. “Individual differences in the visual control of intercepting a penalty kick in association football”. In: *Human Movement Science* 29.3 (2010), pp. 401–411. ISSN: 0167-9457. DOI: 10.1016/j.humov.2010.02.008.

[46] Matt Dicks, Luiz Uehara, and Carlos Lima. “Deception, Individual Differences and Penalty Kicks: Implications for Goalkeeping in Association Football”. In: *International Journal of Sports Science & Coaching* 6.4 (2011), pp. 515–521. DOI: 10.1260/1747-9541.6.4.515.

[47] Florian Baumann, Tim Friehe, and Michael Wedow. “General Ability and Specialization: Evidence From Penalty Kicks in Soccer”. In: *Journal of Sports Economics* 12.1 (2011), pp. 81–105. DOI: 10.1177/1527002510371194.

[48] Terry McMorris and Sion Colenso. “Anticipation of Professional Soccer Goalkeepers When Facing Right-and Left-Footed Penalty Kicks”. In: *Perceptual and Motor Skills* 82.3 (1996), pp. 931–934. DOI: 10.2466/pms.1996.82.3.931.

[49] Jaeho Shim, Rich Masters, Jamie Poolton, and John van der Kamp. “The effect of goalkeepers adopting Muller-Lyer postures”. In: *Journal of Sport & Exercise Psychology* 32 (July 2010), p. 128.

[50] Jaeho Shim, John van der Kamp, Brandon R. Rigby, Rafer Lutz, Jamie M. Poolton, and Richard S. W. Masters. “Taking aim at the Müller–Lyer goalkeeper illusion: An illusion bias in action that originates from the target not being optically specified.” In: *Journal of Experimental Psychology: Human Perception and Performance* 40.3 (2014), pp. 1274–1281. DOI: 10.1037/a0036256.

[51] John van der Kamp and Richard S. W. Masters. “The human Muller-Lyer illusion in goalkeeping”. In: *Perception* 37 (Feb. 2008), pp. 951–954. DOI: 10.1068/p6010.

[52] Daniel Memmert, Stefanie Hüttermann, Norbert Hagemann, Florian Loffing, and Bernd Strauss. “Dueling in the Penalty Box: Evidence-Based Recommendations on How Shooters and Goalkeepers Can Win Penalty Shootouts in Soccer.” In: *International Review of Sport and Exercise Psychology* 6.1 (Sept. 2013), pp. 209–229. DOI: 10.1080/1750984X.2013.811533.

[53] Christos Genakos and Mario Pagliero. “Interim Rank, Risk Taking and Performance in Dynamic Tournaments”. In: *Journal of Political Economy* 120.04 (Aug. 2011), pp. 782–813. DOI: 10.1086/668502.

[54] Daniel C. Hickman and Neil E. Metz. “The impact of pressure on performance: Evidence from the PGA TOUR”. In: *Journal of Economic Behavior & Organization* 116 (2015), pp. 319–330. ISSN: 0167-2681. DOI: 10.1016/j.jebo.2015.04.007.

[55] Julio González-Díaz and Ignacio Palacios-Huerta. “Cognitive performance in competitive environments: Evidence from a natural experiment”. In: *Journal of Public Economics* 139 (2016), pp. 40–52. ISSN: 0047-2727. DOI: 10.1016/j.jpubeco.2016.05.001.

[56] Ashley Marie Fryer, Gershon Tenenbaum, and Graig M. Chow. “Linking performance decline to choking: players’ perceptions in basketball”. In: *Journal of Sports Sciences* 36.3 (2018). PMID: 28271958, pp. 256–265. DOI: 10.1080/02640414.2017.1298829.

[57] Danny Cohen-Zada, Alex Krumer, Mosi Rosenboim, and Offer Moshe Shapir. “Choking under pressure and gender: Evidence from professional tennis”. In: *Journal of Economic Psychology* 61 (2017), pp. 176–190. ISSN: 0167-4870. DOI: 10.1016/j.joep.2017.04.005.

[58] Leo J. Roberts, Mervyn S. Jackson, and Ian H. Grundy. “Choking under pressure: Illuminating the role of distraction and self-focus”. In: *International Review of Sport and Exercise Psychology* 12.1 (2017), pp. 49–69. DOI: 10.1080/1750984X.2017.1374432.

[59] Roy F. Baumeister. “Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance”. In: *Journal of Personality and Social Psychology* 46.3 (1984), pp. 610–620. DOI: 10.1037/0022-3514.46.3.610.

[60] Denise M. Hill, Sheldon Hanton, Nic Matthews, and Scott Fleming. “Choking in sport: a review”. In: *International Review of Sport and Exercise Psychology* 3.1 (2010), pp. 24–39. DOI: 10.1080/17509840903301199.

[61] Irwin G. Sarason. “Anxiety, self-preoccupation and attention”. In: *Anxiety Research* 1.1 (1988), pp. 3–7. DOI: 10.1080/10615808808248215.

[62] Peter Gröpel and Christopher Mesagno. “Choking interventions in sports: A systematic review”. In: *International Review of Sport and Exercise Psychology* 12.1 (2017), pp. 176–201. DOI: 10.1080/1750984X.2017.1408134.

[63] Mark Wilson, Mark Chattington, Dilwyn E. Marple-Horvat, and Nick C. Smith. “A Comparison of Self-Focus versus Attentional Explanations of Choking”. In: *Journal of Sport and Exercise Psychology* 29.4 (2007), pp. 439–456. DOI: 10.1123/jsep.29.4.439.

[64] Philip Furley, Benjamin Noël, and Daniel Memmert. “Attention towards the goalkeeper and distraction during penalty shootouts in association football: a retrospective analysis of penalty shootouts from 1984 to 2012”. In: *Journal of Sports Sciences* 35.9 (2017). PMID: 27292083, pp. 873–879. DOI: 10.1080/02640414.2016.1195912.

[65] Hans Eberspächer, Harmut Gabler, and Erwin Hahn. *Praxis der Psychologie im Leistungssport*. Philippka, Jan. 1990. ISBN: 978-3922067511.

[66] Hubert Makaruk, Jared Marak Porter, Jerzy Sadowski, Anna Bodasińska, Janusz Zieliński, Tomasz Niźnikowski, and Andrzej Mastalerz. “The effects of combining focus of attention and autonomy support on shot accuracy in the penalty kick”. In: *PLOS ONE* 14.9 (Sept. 2019), pp. 1–10. DOI: 10.1371/journal.pone.0213487.

[67] Hubert Makaruk, Jared M. Porter, Anna Bodasińska, and Stephanie Palmer. “Optimizing the penalty kick under external focus of attention and autonomy support instructions”. In: *European Journal of Sport Science* (2020). PMID: 31983301. DOI: 10.1080/17461391.2020.1720829.

[68] Gabriele Wulf. “Attentional focus and motor learning: a review of 15 years”. In: *International Review of Sport and Exercise Psychology* 6.1 (2013), pp. 77–104. DOI: 10.1080/1750984X.2012.723728.

[69] Sebastian Wolf, Ellen Brölz, David Scholz, Ander Ramos-Murguialday, Philipp M. Keune, Martin Hautzinger, Niels Birbaumer, and Ute Strehl. “Winning the game: Brain processes in expert, young elite and amateur table tennis players”. In: *Frontiers in Behavioral Neuroscience* 8.October (Oct. 2014). ISSN: 1662-5153. DOI: 10.3389/fnbeh.2014.00370.

[70] Jordan Muraskin, Jason Sherwin, and Paul Sajda. “Knowing when not to swing: EEG evidence that enhanced perception–action coupling underlies baseball batter expertise”. In: *NeuroImage* 123 (Aug. 2015), pp. 1–10. DOI: 10.1016/j.neuroimage.2015.08.028.

[71] Ming-Yang Cheng, Chiao-Ling Hung, Chung-Ju Huang, Yu-Kai Chang, Li-Chuan Lo, Cheng Shen, and Tsung-Min Hung. “Expert-novice differences in SMR activity during dart throwing”. In: *Biological Psychology* 110 (2015), pp. 212–218. ISSN: 0301-0511. DOI: 10.1016/j.biopsycho.2015.08.003.

[72] Amy J. Haufler, Thomas W. Spalding, D.L. Santa Maria, and Bradley D. Hatfield. “Neuro-cognitive activity during a self-paced visuospatial task: comparative EEG profiles in marksmen and novice shooters”. In: *Biological Psychology* 53.2 (2000), pp. 131–160. ISSN: 0301-0511. DOI: 10.1016/S0301-0511(00)00047-8.

[73] Amy J. Haufler, Thomas W. Spalding, D. Laine Santa Maria, and Bradley D. Hatfield. “Erratum to “Neuro-cognitive activity during a self-paced visuospatial task: comparative EEG profiles in marksmen and novice shooters””. In: *Biological Psychology* 59 (2002), pp. 87–88.

[74] Anmin Gong, Jianping Liu, Ling Lu, Gengrui Wu, Changhao Jiang, and Yunfa Fu. “Characteristic differences between the brain networks of high-level shooting athletes and non-athletes calculated using the phase-locking value algorithm”. In: *Biomedical Signal Processing and Control* 51 (2019), pp. 128–137. ISSN: 1746-8094. DOI: 10.1016/j.bspc.2019.02.009.

[75] Claudio Babiloni, Claudio [Del Percio], Paolo M. Rossini, Nicola Marzano, Marco Iacoboni, Francesco Infarinato, Roberta Lizio, Marina Piazza, Mirella Pirritano, Giovanna Berlutti, Giuseppe Cibelli, and Fabrizio Eusebi. “Judgment of actions in experts: A high-resolution EEG study in elite athletes”. In: *NeuroImage* 45.2 (2009), pp. 512–521. ISSN: 1053-8119. DOI: 10.1016/j.neuroimage.2008.11.035.

[76] Claudio Del Percio, Paolo M. Rossini, Nicola Marzano, Marco Iacoboni, Francesco Infarinato, Pierluigi Aschieri, Andrea Lino, Antonio Fiore, Giancarlo Toran, Claudio Babiloni, and Fabrizio Eusebi. “Is there a ”neural efficiency” in athletes? A high-resolution EEG study”. In: *NeuroImage* 42.4 (2008), pp. 1544–1553. ISSN: 1053-8119. DOI: 10.1016/j.neuroimage.2008.05.061.

[77] Claudio Del Percio, Claudio Babiloni, Nicola Marzano, Marco Iacoboni, Francesco Infarinato, Fabrizio Vecchio, Roberta Lizio, Pierluigi Aschieri, Antonio Fiore, Giancarlo, Michele Gallamini, Marta Baratto, and Fabrizio Eusebi. “”Neural efficiency” of athletes’ brain for upright standing: A high-resolution EEG study”. In: *Brain Research Bulletin* 79.3 (2009), pp. 193–200. ISSN: 0361-9230. DOI: 10.1016/j.brainresbull.2009.02.001.

[78] Frank F. Zhu, Jon P. Maxwell, Yong Hu, Zhiguo G. Zhang, Gilbert W.K. Lam, Jamie M. Poolton, and Richard S.W. Masters. “EEG activity during the verbal-cognitive stage of motor skill acquisition”. In: *Biological Psychology* 84.2 (2010), pp. 221–227. ISSN: 0301-0511. DOI: 10.1016/j.biopsycho.2010.01.015.

[79] F.F. Zhu, J.M. Poolton, M.R. Wilson, J.P. Maxwell, and R.S.W. Masters. “Neural co-activation as a yardstick of implicit motor learning and the propensity for conscious control of movement”. In: *Biological Psychology* 87.1 (2011), pp. 66–73. ISSN: 0301-0511. DOI: 0.1016/j.biopsycho.2011.02.004.

[80] Brad D. Hatfield, Daniel M. Landers, William J. Ray, and F. S. Daniels. “An electroencephalographic study of elite rifle shooters”. In: *The American Marksman* 7 (1982), pp. 6–8.

[81] Brad D. Hatfield, Daniel M. Landers, and William J. Ray. “Cognitive Processes During Self-Paced Motor Performance: An Electroencephalographic Profile of Skilled Marksmen”. In: *Journal of Sport Psychology* 6.1 (1984), pp. 42–59.

[82] Brad D. Hatfield, Daniel M. Landers, and William J. Ray. “Cardiovascuiar-CNS Interactions During a Self-Paced, Intentional Attentive State: Elite Marksmanship Performance”. In: *Psychophysiology* 24.5 (1987), pp. 542–549.

[83] Scott Kerick, Larry Douglass, and Brad Hatfield. “Cerebral cortical adaptations associated with visuomotor practice”. In: *Medicine & Science in Sports & Exercise* 36 (Jan. 2004), pp. 118–129. DOI: 10.1249/01.MSS.0000.106176.31784.D4.

[84] Reyhaneh Nosrati, Kristin Vesely, Tom A. Schweizer, and Vladislav Toronov. “Event-related changes of the prefrontal cortex oxygen delivery and metabolism during driving measured by hyperspectral fNIRS”. In: *Biomedical Optics Express* 7.4 (Apr. 2016), pp. 1323–1335. DOI: 10.1364/BOE.7.001323.

[85] Tom Schweizer, Karen Kan, Yuwen Hung, Fred Tam, Gary Naglie, and Simon Graham. “Brain activity during driving with distraction: an immersive fMRI study”. In: *Frontiers in Human Neuroscience* 7 (2013), p. 53. ISSN: 1662-5161. DOI: 10.3389/fnhum.2013.00053.

[86] Florin Dolcos, Alexandru D. Iordan, and Sanda Dolcos. “Neural correlates of emotion-cognition interactions: A review of evidence from brain imaging investigations”. In: *Journal of Cognitive Psychology* 23.6 (2011). PMID: 22059115, pp. 669–694. DOI: 10.1080/20445911.2011.594433.

[87] Georg Northoff, Andre Richter, Matthias Gessner, Florian Schlagenhauf, Jürgen Fell, Frank Baumgart, Thomas Kaulisch, Rolf Kötter, Klaas E. Stephan, Andreas Leschinger, Tilman Hagner, Bela Bargel, Thomas Witzel, Hermann Hinrichs, Bernhard Bogerts, Henning Scheich, and Hans-Jochen Heinze. “Functional Dissociation between Medial and Lateral Prefrontal Cortical Spatiotemporal Activation in Negative and Positive Emotions: A Combined fMRI/MEG Study”. In: *Cerebral Cortex* 10.1 (Jan. 2000), pp. 93–107. ISSN: 1047-3211. DOI: 10.1093/cercor/10.1.93.

[88] Yohei Nagasawa, Miki Ishida, Yuzo Komuro, Sukekatsu Ushioda, Linzhen Hu, and Kaoru Sakatani. “Relationship Between Cerebral Blood Oxygenation and Electrical Activity During Mental Stress Tasks: Simultaneous Measurements of NIRS and EEG”. In: *Oxygen Transport to Tissue XLI*. Ed. by Pan-Dong Ryu, Joseph C. LaManna, David K. Harrison, and Sang-Suk Lee. Vol. 1232. Cham, Switzerland: Springer, Jan. 2020, pp. 99–104. DOI: 10.1007/978-3-030-34461-0_14.

[89] Nora K. Schaal, Philip Hepp, Adam Schweda, and Oliver T. Wolf. “A Functional Near-Infrared Spectroscopy Study on the Cortical Haemodynamic Responses During the Maastricht Acute Stress Test”. In: *Scientific Reports* 9.1 (Sept. 2019). DOI: 10.1038/s41598-019-49826-2.

[90] Fares Al-shargie, Tong B. Tang, and Masashi Kiguchi. “Mental stress grading based on fNIRS signals”. In: *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, 2016, pp. 5140–5143. DOI: 10.1109/EMBC.2016.7591884.

[91] Thomas Meyer, Tom Smeets, Timo Giesbrecht, Conny W.E.M. Quaedflieg, Fren T.Y. Smulders, Ewout H. Meijer, and Harald L.G.J. Merckelbach. "The role of frontal EEG asymmetry in post-traumatic stress disorder". In: *Biological Psychology* 108 (2015), pp. 62–77. ISSN: 0301-0511. DOI: 10.1016/j.biopsycho.2015.03.018.

[92] Rodrigo Silveira, Raul Cosme Ramos Prado, Cayque Brietzke, Hélio José Coelho-Júnior, Tony Meireles Santos, Flávio Oliveira Pires, and Ricardo Yukio Asano. "Prefrontal cortex asymmetry and psychological responses to exercise: A systematic review". In: *Physiology & Behavior* 208 (2019), p. 112580. ISSN: 0031-9384. DOI: 10.1016/j.physbeh.2019.112580.

[93] Sho Aoki, Jared B Smith, Hao Li, Xunyi Yan, Masakazu Igarashi, Patrice Coulon, Jeffery R Wickens, Tom JH Ruigrok, and Xin Jin. "An open cortico-basal ganglia loop allows limbic control over motor output via the nigrothalamic pathway". In: *eLife* 8 (2019). Ed. by Megan R Carey, Catherine Dulac, and Naoshige Uchida. ISSN: 2050-084X. DOI: 10.7554/eLife.49995.

[94] Clémentine Bosch-Bouju, Brian Hyland, and Louise Parr-Brownlie. "Motor thalamus integration of cortical, cerebellar and basal ganglia information: implications for normal and parkinsonian conditions". In: *Frontiers in Computational Neuroscience* 7 (2013), p. 163. ISSN: 1662-5188. DOI: 10.3389/fncom.2013.00163.

[95] Chris G. Dulla. "Choking on Inhibition in the Reticular Thalamus". In: *Epilepsy Currents* 18.3 (2018), pp. 187–188. DOI: 10.5698/1535-7597.18.3.187.

[96] Antonio Damasio. "Thinking About Brain and Consciousness". In: *Characterizing Consciousness: From Cognition to the Clinic?* Ed. by Dehaene Stanislas and Yves Christen. Vol. 1. Heidelberg, Germany: Springer, 2011, pp. 47–54. DOI: 10.1007/978-3-642-18015-6.

[97] Dean Mobbs, Demis Hassabis, Ben Seymour, Jennifer L. Marchant, Nikolaus Weiskopf, Raymond J. Dolan, and Christopher D. Frith. "Choking on the Money: Reward-Based Performance Decrements Are Associated With Midbrain Activity". In: *Psychological Science* 20.8 (2009), pp. 955–962. DOI: 10.1111/j.1467-9280.2009.02399.x.

[98] Taraz G. Lee and Scott T. Grafton. "Out of control: Diminished prefrontal activity coincides with impaired motor performance due to choking under pressure". In: *NeuroImage* 105 (2015), pp. 145–155. ISSN: 1053-8119. DOI: 10.1016/j.neuroimage.2014.10.058.

[99] Simon B. Eickhoff and Vincent I. Müller. "Functional Connectivity". In: *Brain Mapping*. Ed. by Arthur W. Toga. Waltham: Academic Press, 2015, pp. 187–201. ISBN: 978-0-12-397316-0. DOI: 10.1016/B978-0-12-397025-1.00212-8.

[100] Wesley C. Clapp, Michael T. Rubens, and Adam Gazzaley. "Mechanisms of Working Memory Disruption by External Interference". In: *Cerebral Cortex* 20.4 (July 2009), pp. 859–872. ISSN: 1047-3211. DOI: 10.1093/cercor/bhp150.

[101] Jong H. Yoon, Clayton E. Curtis, and Mark D'Esposito. "Differential effects of distraction during working memory on delay-period activity in the prefrontal cortex and the visual association cortex". In: *NeuroImage* 29.4 (2006), pp. 1117–1126. ISSN: 1053-8119. DOI: 10.1016/j.neuroimage.2005.08.024.

[102] Jens C. Pruessner, Katarina Dedovic, Najmeh Khalili-Mahani, Veronika Engert, Marita Pruessner, Claudia Buss, Robert Renwick, Alain Dagher, Michael J. Meaney, and Sonia Lupien. "Deactivation of the Limbic System During Acute Psychosocial Stress: Evidence From Positron Emission Tomography and Functional Magnetic Resonance Imaging Studies". In: *Biological Psychiatry* 63.2 (2007), pp. 234–240. DOI: 10.1016/j.biopsych.2007.04.041.

[103] Rongjun Yu. "Choking under pressure: the neuropsychological mechanisms of incentive-induced performance decrements". In: *Frontiers in Behavioral Neuroscience* 9 (2015).

[104] Erno J. Hermans, Hein J. F. van Marle, Lindsey Ossewaarde, Marloes J. A. G. Henckens, Shaozheng Qin, Marlieke T. R. van Kesteren, Vincent C. Schoots, Helena Cousijn, Mark Rijpkema, Robert Oostenveld, and Guillén Fernández. "Stress-Related Noradrenergic Activity Prompts Large-Scale Neural Network Reconfiguration". In: *Science* 334.6059 (2011), pp. 1151–1153. DOI: 10.1126/science.1209603.

[105] John J.B. Allen, James A. Coan, and Maria Nazarian. "Issues and assumptions on the road from raw signals to metrics of frontal EEG asymmetry in emotion". In: *Biological Psychology* 67.1 (2004). Frontal EEG Asymmetry, Emotion, and Psychopathology, pp. 183–218. ISSN: 0301-0511. DOI: 10.1016/j.biopsycho.2004.03.007.

[106] Daniel Landers, Myungwoo Han, Walter Salazar, and Steven Petruzzello. "Effects of learning on electroencephalographic and electrocardiographic patterns in novice archers". In: *International Journal of Sport Psychology* 25 (Jan. 1994), pp. 313–330.

[107] Germano Gallicchio, Thomas Finkenzeller, Gerold Sattlecker, Stefan Lindinger, and Kerstin Hoedlmoser. "Shooting under cardiovascular load: Electroencephalographic activity in preparation for biathlon shooting". In: *International Journal of Psychophysiology* 109 (2016), pp. 92–99. ISSN: 0167-8760. DOI: 10.1016/j.ijpsycho.2016.09.004.

[108] Joachim Taelman, S. Vandeput, A. Spaepen, and S. Van Huffel. "Influence of Mental Stress on Heart Rate and Heart Rate Variability". In: *4th European Conference of the International Federation for Medical and Biological Engineering*. Ed. by Jos Vander Sloten, Pascal Verdonck, Marc Nyssen, and Jens Haueisen. Berlin, Heidelberg: Springer Berlin Heidelberg, 2009, pp. 1366–1369.

[109] Martina Navarro, Nelson Miyamoto, John van der Kamp, Edgard Morya, Ronald Ranvaud, and Geert J.P. Savelsbergh. "The Effects of High Pressure on the Point of No Return in Simulated Penalty Kicks". In: *Journal of Sport and Exercise Psychology* 34.1 (2012), pp. 83–101.

[110] Martina Navarro, Nelson Miyamoto, John van der Kamp, Edgard Morya, Geert J. P. Savelsbergh, and Ronald Ranvaud. "Differential effects of task-specific practice on performance in a simulated penalty kick under high-pressure". In: *Psychology of Sport and Exercise* 14.5 (2013), pp. 612–621. ISSN: 1469-0292. DOI: 10.1016/j.psychsport.2013.03.004.

[111] Gareth Paterson, John van der Kamp, and Geert Savelsbergh. "Moving Advertisements Systematically Affect Gaze Behavior and Performance in the Soccer Penalty Kick". In: *Frontiers in Sports and Active Living* 1 (2020), pp. 69–78. ISSN: 2624-9367. DOI: 10.3389/fspor.2019.00069.

[112] Muhammad A. Kamran, Malik M. Naeem Mannan, and Myung-Yung Jeong. “Initial-Dip Existence and Estimation in Relation to DPF and Data Drift”. In: *Frontiers in Neuroinformatics* 12 (2018), p. 96. DOI: `10.3389/fninf.2018.00096`.

[113] Sabrina Brigadoi, Lisa Ceccherini, Simone Cutini, Fabio Scarpa, Pietro Scatturin, Juliette Selb, Louis Gagnon, David A. Boas, and Robert J. Cooper. “Motion artifacts in functional near-infrared spectroscopy: A comparison of motion correction techniques applied to real cognitive data”. In: *NeuroImage* 85 (2014). Celebrating 20 Years of Functional Near Infrared Spectroscopy (fNIRS), pp. 181–191. ISSN: 1053-8119. DOI: `10.1016/j.neuroimage.2013.04.082`.

[114] Tomoyuki Hiroyasu, Yuka Nakamura, and Hisatake Yokouchi. “Method for removing motion artifacts from fNIRS data using ICA and an acceleration sensor”. In: *2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* (2013), pp. 6800–6803. DOI: `10.1109/EMBC.2013.6611118`.

[115] Frank A. Fishburn, Ruth S. Ludlum, Chandan J. Vaidya, and Andrei V. Medvedev. “Temporal Derivative Distribution Repair (TDDR): A motion correction method for fNIRS”. In: *NeuroImage* 184 (2019), pp. 171–179. DOI: `10.1016/j.neuroimage.2018.09.025`.

[116] Silvia Benavides-Varela and Judit Gervain. “Learning word order at birth: A NIRS study”. In: *Developmental Cognitive Neuroscience* 25 (2017). Sensitive periods across development, pp. 198–208. ISSN: 1878-9293. DOI: `10.1016/j.dcn.2017.03.003`.

[117] Thien Nguyen, Olajide Babawale, Tae Kim, Hang J. Jo, Hanli Liu, and Jae G. Kim. “Exploring brain functional connectivity in rest and sleep states: a fNIRS study”. In: *Scientific Reports* 8.16144 (Nov. 2018). DOI: `10.1038/s41598-018-33439-2`.

[118] Jaimie F. Veale. “Edinburgh Handedness Inventory - Short Form: A revised version based on confirmatory factor analysis”. In: *Laterality* 19.2 (May 2013). DOI: `10.1080/1357650X.2013.783045`.

[119] Rainer Martens. *Sport Competition Anxiety Test*. Champaign, Illinois: Human Kinetics Publishers, 1977.

[120] Damon Burton Rainer Martens Robin S. Vealey. *Competition Anxiety in Sport*. Champaign, Illinois: Human Kinetics Publishers, 1990.

[121] Robert Wood. *About the Sport Competition Anxiety Test (SCAT)*. 2017. URL: `https://www.topendsports.com/psychology/scat.htm` (visited on 10/22/2020).

[122] Robert Wood. *The Sport Anxiety Scale (SAS)*. 2017. URL: `https://www.topendsports.com/psychology/sas.htm` (visited on 10/26/2020).

[123] Ronald E. Smith, Frank L. Smoll, and Robert W. Schutz. “Measurement and correlates of sport-specific cognitive and somatic trait anxiety: The sport anxiety scale”. In: *Anxiety Research* 2.4 (1990), pp. 263–280. DOI: `10.1080/08917779008248733`.

[124] Ronald Smith, Frank Smoll, Sean Cumming, and Joel Grossbard. “Measurement of Multidimensional Sport Performance Anxiety in Children and Adults: The Sport Anxiety Scale-2”. In: *Journal of sport & Exercise Psychology* 28 (Dec. 2006), pp. 479–501. DOI: `10.1123/jsep.28.4.479`.

[125] Meryem A. Yücel, Juliette Selb, Robert J. Cooper, and David A. Boas. "Targeted principle component analysis: A new motion artifact correction approach for near-infrared spectroscopy". In: *Journal of Innovative Optical Health Sciences* 07.02 (2014), p. 1350066. DOI: 10.1142/S1793545813500661.

[126] Xu Cui, Signe Bray, and Allan L. Reiss. "Functional near infrared spectroscopy (NIRS) signal improvement based on negative correlation between oxygenated and deoxygenated hemoglobin dynamics". In: *NeuroImage* 49.4 (2010), pp. 3039–3046. ISSN: 1053-8119. DOI: 10.1016/j.neuroimage.2009.11.050.

[127] Gihyoun Lee, Sang H. Jin, Seong T. Yang, Jinung An, and Berdakh Abibulaev. "Cross-correlation between HbO and HbR as an effective feature of motion artifact in fNIRS signal". In: *2018 6th International Conference on Brain-Computer Interface (BCI)*. 2018, pp. 1–3. DOI: 10.1109/IWW-BCI.2018.8311513.

[128] Katherine L. Perdue, Alissa Westerlund, Sarah A. McCormick, and Charles A. Nelson III. "Extraction of heart rate from functional near-infrared spectroscopy in infants". In: *Journal of Biomedical Optics* 19.6 (2014), pp. 1–8. DOI: 10.1117/1.JBO.19.6.067010.

[129] Peter Welch. "The use of fast Fourier transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms". In: *IEEE Transactions on Audio and Electroacoustics* 15.2 (1967), pp. 70–73. DOI: 10.1109/TAU.1967.1161901.

[130] Rong-Chao Peng, Xiao-Lin Zhou, Wan-Hua Lina, and Yuan-Ting Zhang. "Extraction of Heart Rate Variability from Smartphone Photoplethysmograms". In: *Computational and Mathematical Methods in Medicine* 2015 (2015), p. 11. DOI: 10.1155/2015/516826.

[131] Mahya Mirbagheri, Naser Hakimi, Elias Ebrahimzadeh, and S. Kamaledin Setarehdan. "Quality analysis of heart rate derived from functional near-infrared spectroscopy in stress assessment". In: *Informatics in Medicine Unlocked* 18 (2020), p. 100286. ISSN: 2352-9148. DOI: 10.1016/j.imu.2019.100286.

[132] Mehrdad Dadgostar, Seyed Kamaledin Setarehdan, Sohrab Shahzadi, and Ata Akin. "Classification of schizophrenia using SVM via fNIRS". In: *Biomedical Engineering: Applications, Basis and Communications* 30.02 (2018), p. 1850008. DOI: 10.4015/S1016237218500084.

[133] Behnam Molavi, Lillian Anne May, Judit Gervain, Manuel Carreiras, Janet F. Werker, and Guy Albert Dumont. "Analyzing the resting state functional connectivity in the human language system using near infrared spectroscopy". In: *Frontiers in Human Neuroscience* 7 (Jan. 2014). DOI: 10.3389/fnhum.2013.00921.

[134] Ruixue Lie, Erin Walker, Leah Friedman, Catherine M. Arrington, and Erin T. Solovey. "fNIRS-based classification of mind-wandering with personalized window selection for multimodal learning interfaces". In: *Journal on Multimodal User Interfaces* (2020). DOI: 10.1007/s12193-020-00325-z.

[135] Archana K. Singh and Ippeita Dan. "Exploring the false discovery rate in multichannel NIRS". In: *NeuroImage* 33.2 (2006), pp. 542–549. ISSN: 1053-8119. DOI: 10.1016/j.neuroimage.2006.06.047.