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„Positionsspezifische Unterschiede von Exekutiven Funktionen im Handball“ / „Position-specific differences in Executive Functions in team handball”

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Abstract English

Team handball is a dynamic open-skill sport with diverse cognitive demands. Although past studies indicated the importance of executive functions in open-skill athletes, only limited research has been conducted about executive functions of handball players. The aim of the current study was to explore different levels of executive functions in handball players according to playing position. Eighty-two male and female Austrian handball players (mean age 17.38 ± 2.58), who mainly competed on a national or international level, participated in several executive function tests (Design Fluency test, flanker task, 2-back task) and were rated based on their game intelligence by their coaches. Analysis revealed a few differences between the playing positions: playmakers exhibited higher inhibitory control and cognitive flexibility measures, back players outperformed non-back players in terms of cognitive flexibility measures and goalkeepers showed lower cognitive flexibility levels compared to other playing positions. No significant position-specific difference regarding game intelligence was detected. Altogether, results suggested higher executive functions in playmakers and partially in back players than in wings, pivots, and goalkeepers. However, further research is needed to confirm these findings and to examine cognitive profiles of pivots, wings, and left and right back players thoroughly.

Abstract German

Handball ist eine dynamische Spielsportart mit zahlreichen kognitiven Anforderungen. Obwohl frühere Forschung bereits zeigte, dass Exekutive Funktionen eine zentrale Rolle in Spielsportarten einnehmen, beschäftigten sich bisher nur wenige Studien mit Exekutiven Funktionen von Athlet:innen im Handballsport. Daher war es das Ziel dieser Studie, die Ausprägungen von Exekutiven Funktionen von Handballspieler:innen anhand unterschiedlicher Spielpositionen zu untersuchen. 82 weibliche und männliche deutschsprachige Handballspieler:innen (Mittelwert Alter 17,38 ± 2,58), die auf nationalem oder internationalem Leistungsniveau spielten, absolvierten verschiedene kognitive Leistungstests (Design Fluency Test, Flanker Test, 2-back Test). Außerdem bewerteten Trainer:innen die Spielintelligenz ihrer Athlet:innen. Die Analysen zeigten einige wenige Unterschiede zwischen den Spielpositionen: Rückraum Mitte Spieler:innen erzielten die besten Werte in der Inhibition und der Kognitiven Flexibilität von allen Spielpositionen, Rückraum Spieler:innen wiesen eine höhere Ausprägung in der Kognitiven Flexibilität auf als Spieler:innen, die nicht am Rückraum spielten, und Torhüter:innen zeigten die niedrigste Ausprägung in der Kognitiven Flexibilität im Vergleich zu allen anderen Positionen. Es wurde kein signifikanter Unterschied in der Spielintelligenz zwischen den Spielpositionen gefunden. Die Ergebnisse dieser Studie deuten darauf hin, dass die Exekutive Funktionen von Rückraum Mitte Spieler:innen und teilweise auch von Rückraum Spieler:innen höher ausgeprägt sind als jene von Kreisläufer:innen, Flügelspieler:innen und Torhüter:innen. Um die Ergebnisse dieser Studie zu bestätigen, braucht es zukünftig weitere Studien, die die kognitiven Profile von den verschiedenen Spielpositionen im Handball untersuchen.

Table of contents

1. Introduction

Team handball is a dynamic sport game (Kiss & Balogh, 2019), which is characterized by multiple rapid movements and decisions. In order to be successful at this sport, handball players need to have several physical skills such as strength, endurance and agility (Michalsik & Aagaard, 2014). In addition to physical, tactical and technical components, psychological and cognitive skills seem to be important in handball as well, although there is only limited research about cognitive factors in handball. Wagner, Finkenzeller, Würth, and von Duvillard (2014) name attention, decision making and executive functioning as important cognitive aspects in team handball. In the past, some studies about executive functions (EFs) in sport have already been conducted and the debate of their significance in sport is still very relevant. Executive functions are defined as mental processes which make it possible to not react automatically and impulsively but *'mentally playing with ideas; taking the time to think before acting; meeting novel, unanticipated challenges; resisting temptations; and staying focused'* (Diamond, 2013, p. 1). In a handball game, players have to process lots of different impressions simultaneously and need to be able to decide and react very quickly. Furthermore, handball is a sport that includes constantly changing conditions (Biscaia et al., 2021) and players need to be able to change their original plans rapidly. This, for example, is the case when the defense reacts in a different way than expected or when the attacking team suddenly loses the ball and then has to defend their goal. It can therefore be assumed that handball players have to permanently use their EFs throughout the game to be successful. The playing positions in team handball have quite different physical, technical (Kromer, 2015) and probably also cognitive demands. Playmakers usually take the lead in the game and, together with back players, they have to "read" the game (Kolodziej, 2010), whereas wing players have to switch particularly quickly between defending and attacking situations and goalkeepers need to have typical shooting performances of the opposing players in mind and react accordingly and extremely quickly. This raises the question whether the level of executive functions differs due to playing position. Even though several studies in the past have emphasized the correlation between EFs and sport performance (e.g. Cona et al., 2015; Elferink-Gemser et al., 2018; Vestberg, Reinebo, Maurex, Ingvar, & Petrovic, 2017), there are only a few studies that have already examined EFs in team sport according to playing position. The purpose of this study is to investigate if different levels of executive functions in team handball players according to playing position do exist. The understanding of differences in executive functions according to playing position could help coaches with the selection of positions for youth players, contribute to the talent identification process and further make it possible to give recommendations about position-specific cognitive training interventions.

1.1. Definition of Executive Functions

Executive functions (EFs) are higher cognitive functions that are essential for everyday life and for people's health (Diamond, 2013). They are linked to the prefrontal cortex (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). EFs help with controlling one's thoughts and behavior and are needed in situations with new demands when automatic responses are unwanted, as well as in situations when one pursues a goal in spite of distractions (Unsworth et al. 2009). Therefore, the concept of EFs is often associated with goal-oriented behavior (e.g. Alvarez & Emory, 2006; Best & Miller, 2010). One has to use EFs whenever it is inappropriate or not desired to react automatically and by habits but when one thinks about what to do next instead. Diamond (2013, p. 1) describes EFs as follows: *'Executive functions [...] refer to a family of top-down mental processes needed when you have to concentrate and pay attention, when going on automatic or relying on instinct or intuition would be ill-advised, insufficient, or impossible.'* Some researchers are still debating about the independence of EFs from other cognitive constructs and which subcomponents can be assigned to EFs (Ionsecu, 2012). However, well-known literature about EFs agrees on three core subcomponents: inhibition (inhibitory control), cognitive flexibility (shifting) and working memory (updating) (Miyake et al., 2000; Diamond, 2013; Best & Miller, 2010). Thus, this work will focus on these three core EFs, which are related but are also distinguishable from each other (Miyake et al., 2000; Unsworth et al., 2009). On the one hand, EFs are based on other, lower cognitive functions, such as visual-spatial perception and short-term memory, and are further able to regulate these 'lower-level' cognitive functions (Alvarez & Emory, 2006). On the other hand, the three core EFs form the basis for higher-order executive functions such as reasoning, problem-solving and planning (Diamond, 2013). Research about EFs has its origin in neuropsychological areas and previously investigated lots of patients with frontal lobe damage (Miyake et al., 2000).

1.1.1. Inhibition

Inhibition, also called 'inhibitory control', enables people to manage and get in control of their behavior, thoughts, and emotions (Diamond, 2013). Miyake et al. (2000, p. 57) explain that research provides several different definitions of inhibition and describe it in their work as: *'one's ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary.'* Inhibition is used whenever someone withholds an impulse and resists to react in an automatic way and instead can choose between possible further steps. This part of being able to choose the next step instead of reacting impulsively enables one to select a suitable and more sensible behavior for the goal that is pursued (Wang et al., 2013). Diamond (2013) generally distinguishes between two different facets of inhibition: interference control and response inhibition. Interference control can further be divided in two subcategories, namely selective attention and cognitive inhibition. First, interference control makes it possible to decide what to concentrate on and which stimuli from the environment to suppress. This means being able to *'selectively attend'* (Diamond, 2013, p. 2). For example, selective attention makes it possible for someone to choose on whom to concentrate when two people are talking at the same time by suppressing one of the two. Therefore, it is logical that this ability displays an essential prerequisite for nearly every instance of interpersonal communication. Second, interference control means being able to suppress undesired thoughts and memories that could get in the way of one's overarching goal. This component of interference control is called *'cognitive inhibition'* (Diamond, 2013, p. 2) and exhibits a strong connection to working memory. Intentional forgetting represents an example for this aspect of interference control. Another facet of inhibition, namely response inhibition and more specifically self-control, enables us to control our reaction and behavior. By means of self-control, one can choose to not react impulsively when, for example, one wants to say something important but nevertheless waits until another person has stopped speaking instead of interrupting them. Furthermore, self-control enables one to keep the focus on a particular task despite diversions from the environment or from distractions coming from oneself such as undesired thoughts or emotions. Therefore, without self-control, it would hardly ever be possible to pursue any longer lasting task such as studying for an exam for weeks or finishing a complex and tiring project at work (Diamond, 2013). Hence, it should seem natural that the ability of inhibition is needed in everyday life.

1.1.2. Working Memory

The ability to use one's working memory makes it possible to not only remember information but also to mentally adapt and change the information in one's mind (Diamond, 2013). In order to do so, the information has to be stored in the working memory for a brief period of time without the presence of any external cues about the information in the environment (Best & Miller, 2010). Diamond (2013, p. 7) describes that working memory generally *'involves holding information in mind and mentally working with it'*. This process of changing the information differs from the short-term memory, which only stores unmodified information from the past. Thus, short-term memory and working memory are associated with different neural areas of the prefrontal cortex (Diamond, 2013). Working memory, also called *'updating'* in Miyake et al. (2000, p. 57), provides one with information from the past, but it further enables one to manipulate this information in a desired way. This process of 'updating' the information represents the core skill of working memory and makes the previous information applicable for the present situation. In order to have the relevant information at hand, the updating function deletes older and insignificant information and checks the relevance of new information for the current task (Miyake et al., 2000). Therefore, working memory is needed for making decisions for the future including taking relevant information from the past into account. For example, working memory is needed when reading an essay and not only remembering but also adjusting the previously read information in one's mind for understanding the novel arguments. Moreover, working memory is essential for mentally calculating and holding something in mind and using it later on. The latter, for example, helps one to gather relevant information in order to find a reasonable argumentation in a discussion. Finally, Diamond (2013) explains that working memory plays a vital role in finding creative solutions. By means of working memory, one is able to identify possible connections between things that do not share a lot of commonalities at first sight and to mentally take apart facets of something that seems to supposedly be an entity. And because creativity stands for being able to rearrange elements in novel and different ways, creativity is based on working memory. Inhibitory control and working memory show a strong connection to one another. They are built on and support each other, and are very often, or possibly always, used simultaneously. To give an example, one must be able to remember what they want to focus on (working memory) in order to know which external information or internal thought to suppress (inhibitory control). Furthermore, by sufficiently suppressing unwanted thoughts (inhibitory control), it is easier to mentally adapt the information in one's mind (working memory). Without any inhibitory control, it is not possible to successfully use one's working memory and vice versa (Diamond, 2013).

1.1.3. Cognitive Flexibility

The third core executive function is cognitive flexibility, also known as 'shifting' or 'switching'. Literature provides a multitude of different definitions of cognitive flexibility (Ionsecu, 2012). When addressing the 'shifting' aspect of cognitive flexibility, a well-known and commonly used characterization was presented by Miyake et al. (2000). They define shifting as the ability to switch between tasks, rules or mental sets and further distinguish between attention and task switching. For example, a task where someone first has to focus on or react to a certain stimulus A (e.g. numbers) and then to a stimulus B (e.g. letters), requires set shifting. Ionescu (2012) as well as Diamond (2013) define cognitive flexibility slightly differently than solely shifting between mental sets, although Diamond (2013) uses cognitive flexibility, mental flexibility, and set shifting substantially synonymously. Ionescu (2012) describes the concept as follows (p. 190): *'Cognitive flexibility [...] helps humans pursue complex tasks, such as multitasking and finding novel, adaptable solutions to changing demands.'* Diamond (2013) distinguishes between two different facets of cognitive flexibility. First, cognitive flexibility is characterized by changing perspectives and consider something from a different point of view. Second, cognitive flexibility means being able to change the way of thinking about something, to think *'outside the box'* (Diamond, 2013, p. 14) and it represents the opposite of being rigid and stuck in one's old behaviors and thoughts. To give an example, when a problem-solving strategy is not working as expected, one needs cognitive flexibility to look at the problem from a different point of view and adapt or change the strategy completely. Moreover, to admit having committed a mistake, to thoroughly consider a different perspective from another person about a controversial topic, and to sufficiently adjust to permanently changing demands requires cognitive flexibility (Diamond, 2013). In contrast to that, being stuck in old behavior patterns and not adjusting to new environmental demands, even though the old behaviors are obviously not sufficient, means being rigid and inflexible. As a prerequisite for being cognitively flexible, one must be able to control attention and behavior (inhibition) and keep information in mind and manipulate it (working memory). For example, switching to a different task or rule (e.g. first reacting to numbers, then to letters) requires the ability to suppress the old task (inhibition) and to hold the new rule or task in mind and think about it (working memory). Thus, cognitive flexibility depends on inhibition and working memory and, naturally, develops later than the other two core executive functions. Cognitive flexibility further is associated with successful problem solving and creativity (Ionsecu, 2012; Diamond, 2013).

1.1.4. Development and importance of Executive Functions

EFs start to develop very early in childhood. Young children are already able to successfully perform an easy switching task, which represents a simple aspect of cognitive flexibility, at the age of 3 to 5 (Diamond, 2013). However, even though EFs start to evolve quite early after birth, they take a lot of time until their outright development (Best & Miller, 2010). For example, young children often have problems with waiting, which basically means failing to suppress a certain unwanted behavior (inhibition), such as waiting for one's turn to say something instead of interrupting others. Interestingly, the ability to control one's behavior in childhood has turned out to be a predictor of the level of health, personal finances, and quality of life in adulthood. Children with a higher level of self-control tend to be physically and mentally healthier, lead a happier life and make more money in their jobs as adults than children with low self-control (Moffitt et al., 2012, as cited in Diamond, 2013, p. 7). Thus, the EF levels in early childhood are connected with success and quality of life in adulthood. After childhood, the development of EFs continues over youth and adolescence and stabilizes around the age of 19 (Vestberg et al., 2017). As cognitive flexibility is based on inhibitory control and working memory, it develops later than the other two core EFs. Later on in life while aging, EFs decline gradually. Older adults are more prone to external distractions and hence show a lower level of inhibition and working memory (Diamond, 2013). Altogether, EFs play a major role in everyday life and for being successful in modern society. EFs are needed for every interpersonal relationship, at work, and for academic achievements. Furthermore, literature displays a connection between EFs and success in school, success at work, marital harmony, public safety, and quality of life (Diamond, 2013). In contrast to that, impairment of EFs is associated with personality disorders such as aggressive behavior (Unsworth et al., 2009) as well as mental disorders such as ADHD, addiction, and depression. This paragraph highlights the importance and indispensability of EFs in every facet of people's lives.

1.1.5. Related terms

According to Diamond (2013), inhibitory control exhibits a distinct link to the process of self-regulation. Nevertheless, self-regulation regards regulating one's emotions and thoughts in a desired way, whereas inhibition is defined as the ability to exclusively suppress unwanted thoughts and emotions or prepotent responses. Furthermore, higher executive functions such as planning, reasoning, and problem-solving are based on the three core EFs. Fluid intelligence also exhibits a connection to EFs. Unsworth et al. (2009), for example, confirmed that each of the three core EFs is related to fluid intelligence and Diamond (2013) equates fluid intelligence to reasoning and problem-solving. The connection between the three core EFs and higher-order EFs is presented in the following table.

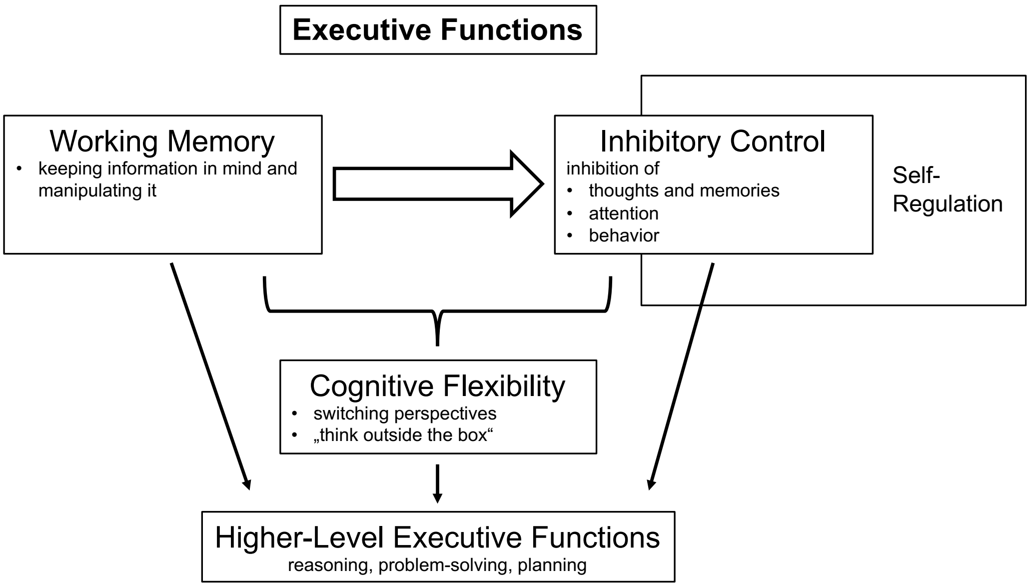

Figure 1: construct of executive functions and related terms (modified according to Diamond, 2013)

1.2. Executive functions in sport

When attempting to define the determining factors for high sport performance, literature names perceptual and cognitive skills right next to motor control as highly important (e.g. Cona et al., 2015; Lundgren et al., 2016; Scharfen & Memmert, 2019). As already mentioned, it is possible to distinguish between lower-level and higher-level cognitive functions. Studies in sport science that focused on these lower-level cognitive functions, such as basic information processing including reaction time and visuo-perceptual abilities, mainly did not find a clear link to sport performance, albeit with a few exceptions (Huijgen et al., 2015). Recently, however, interest in higher-level cognitive functions, namely EFs, has grown in sport research (Finkenzeller, Krenn, Würth, & Amesberger, 2021). It seems obvious that abilities such as quickly processing information and adapting to changing demands display, among others, essential factors in several sports. Inhibitory control, for example, is not only a crucial skill in everyday life but also in the sporting context. Being able to suppress undesired external stimuli is, for example, needed in endurance sports, when an athlete has to stay focused during a competition and resist distractions, such as unhelpful thoughts. Moreover, inhibiting a planned action exhibits a vital factor in team sports, when, for example, a defender is suddenly blocking the way to a team colleague, to whom the player originally wanted to pass the ball. Finally, Beavan et al. (2019) explained the importance of inhibition as a prerequisite for effective decision-making in soccer, in order to be able to suppress an intended action, which does not seem to be the best option anymore, and instead choose a much wiser option. Working memory enables athletes in team sports to remember important playing options and thus choose positions in soccer (Huijgen et al., 2015). Furthermore, athletes of racket sports such as badminton or tennis need to memorize their opponents' typical playing habits and act based on this knowledge. And finally, all team sports require cognitive flexibility to a great extent. Team sports athletes need to make decisions under extreme time pressure and are mainly acting in unpredictable situations, as the opponents and team colleagues are permanently moving and changing their positions. During the game, they often have to change or adapt their strategy when it is not possible to pursue a planned strategy anymore or a better opportunity suddenly comes up. Soccer players, for example, are constantly attempting to find the best option: is dribbling the ball, passing the ball to a team colleague or performing a shot on the goal the best option in this specific situation? Finally, rapidly switching between offense and defense situation also requires a certain level of cognitive flexibility (Huijgen et al., 2015). Based on these examples, it seems reasonable that every sport needs EFs to a certain extent. The next paragraphs will offer a brief overview of the most important findings concerning EFs and sport for this work.

Past research has found that a high level of EFs plays a significant role in sports (Krenn et al., 2018). Vestberg et al. (2012) were the first to not only show that high division soccer players surpassed low division players in terms of EFs, but that their EF levels also predicted the players' goals and assists two seasons later. Several other studies followed this finding, addressing EFs and sport performance in all kinds of sports. Many of them confirmed the connection between EF levels and sport performance. To give some examples, elite athletes exhibited better EF scores than amateur or non-elite athletes in ultra-marathon (Cona et al., 2015), table tennis (Elferink Gemser et al., 2018), soccer (Vestberg et al., 2017; Huijgen et al., 2015; Verburgh, Scherder, van Lange, & Oosterlaan, 2014), and ice-hockey (Lundgren et al., 2016). Furthermore, various studies have shown that athletes outperform non-athletes in EF assessments. For example, athletes of different sports showed higher levels of inhibition and problem-solving than non-athletes in Jacobson and Matthaeus (2014), high and low-division soccer players scored higher than the norm group in EF measures in Vestberg et al. (2012), and the same was true for ice-hockey players in Lundgren et al. (2016), showing enhanced EF skills in contrast to the norm group.

However, there is an ongoing debate in sport psychological research about the potential transfer of cognitive skills in sports to other areas. The cognitive skill transfer hypothesis proposes that comprehensive experience in a cognitively demanding task may have an influence on other, general cognitive tasks, which exhibit similarities to the sporting context, but are yet untrained (Jacobson & Matthaeus, 2014; Krenn et al., 2018). Scientists are discussing the range of this transfer and, more specifically, how far extensive training, that requires cognitive abilities, in sports leads to an enhancement in basic cognitive skills in sport-unspecific tasks (Jacobson & Matthaeus, 2014; Furley & Memmert, 2011). Two different hypotheses form the basis for this debate and research in the sport area offers ambiguous evidence in both directions. The narrow transfer hypothesis implies that extensive training in a cognitively demanding activity, such as team sports or chess, does not result in a higher level of cognitive abilities, such as memory capacity and perceptual skills, beyond the specific domain in which the individual has a lot of experience (Furley & Memmert, 2011). According to this hypothesis, handball players, for example, would solely outperform non-athletes in cognitive tasks that are directly related to team handball and their basic cognitive abilities would not differ from non-athletes when executing a sport-unspecific cognitive task. Evidence for this hypothesis was, among others, provided by Furley and Memmert (2010), who found no differences in visuospatial abilities between basketball players and non-athletes. In contrast to this, researchers detected indications for a different perspective regarding a certain transfer of cognitive skills from sports to other areas, namely the broad transfer hypothesis. This hypothesis assumes that cognitive abilities, that are trained in a specific environment, can translate into other areas. By means of this hypothesis, expert chess players would exceed novices in general cognitive abilities and team sport athletes would show enhanced cognitive skills compared to non-athletes in a sport-unspecific task (Furley & Memmert, 2011). Voss, Kramer, Bask, Prakash, and Roberts (2010) conducted a meta-analysis and detected small-to-medium-sized differences in processing speed and other attentional paradigms between athletes and non-athletes in favor of athletes. Therefore, according to the broad cognitive skill transfer hypothesis, extensive training in a cognitively demanding environment, such as team sports, can lead to '*particular cognitive skill profiles'* (Voss et al., 2010, p. 822). Consequently, the above-mentioned findings that athletes outperform non-athletes in terms of general cognitive abilities and EFs (e.g. Voss et al., 2010; Jacobson & Matthaeus; Vestberg et al., 2012) can on the one hand be interpreted as a support for the broad transfer hypothesis. This is because athletes, according to these studies, showed higher scores in general cognitive skills and EF assessments that were not directly trained in their specific sport. Therefore, a possible transfer from the cognitive demands of their specific sport to other domains could be the reason for these higher EF levels compared to non-athletes. On the other hand, Furley and Memmert (2011) provided arguments against this line of reasoning regarding EF differences in athletes and non-athletes and their support for the broad transfer hypothesis. They argued that, based on these results, it is not possible to justify a causal relationship that athletes show superior EFs because of their extensive training in a cognitively demanding sport. The question remains whether experiences in cognitively demanding sports lead to higher cognitive skills in other areas, or if people, who naturally display higher cognitive skills, are just more likely to participate in these sports with high cognitive demands. Furthermore, they addressed the aspect that high fitness levels also enhance cognitive abilities, and this could also explain higher EF levels in athletes compared to non-athletes.

Nevertheless, the hypothesis that extensive training in a cognitively demanding area results in specific cognitive profiles was supported by researchers, who found differences in EFs with respect to sport type (e.g. Krenn et al., 2018; Jacobson & Matthaeus, 2014). Studies in the past concluded that athletes of open-skill sports show a higher level of some EF facets than those of closed-skill sports (e.g. Koch & Krenn, 2021; Krenn et al., 2018; Pacesová, Smela, & Nemcek, 2020, Wang et al., 2013). Open-skill sports are characterized by numerous external stimuli and changes in the sporting environment, to which athletes have to react and adjust. Hence, open-skill sports such as handball, soccer or basketball are externally paced. Conversely, closed-skill sports such as endurance sports (e.g. running, swimming) are self-paced. Closed-skill athletes typically perform their sport in a mostly predictable and unaffected environment and do not need to react to many external stimuli (Wang et al., 2013). More specifically, Jacobson and Matthaeus (2014) found a difference between externally paced (open-skill) athletes and self-paced (closed-skill) athletes in problem solving abilities in favor of externally paced athletes, whereas self-paced athletes performed better at inhibition tasks. The category open-skill sport can further be divided in interceptive sports such as tennis, and strategic sports, which consist of several opponents and team colleagues (e.g. soccer). Krenn et al. (2018) investigated EF levels of elite athletes and reported higher levels in cognitive flexibility and partly working memory in elite athletes of strategic sports compared to those of static sports (closed-skill). Thus, the authors argued that extensive training in strategic sports is more likely to affect general cognitive abilities than comprehensive experiences in static sports. The findings concerning differences of EFs between open and closed-skill elite athletes were reproduced by Koch and Krenn (2021). Additionally, the aforementioned authors found an influence of sport participation in adolescence until the age of 18. Participation in open-skill sports in youth was accompanied by higher levels of EFs, which was especially true for closed-skill athletes. This finding seems quite obvious because of the above-mentioned connection between open-skill sports and higher EF levels. However, open-skill elite athletes benefitted from prior participation in closed-skill sports when it comes to cognitive flexibility. According to these results, broad experiences in various sport contexts seem to have a connection with EF development (Koch & Krenn, 2021).

The previously mentioned findings concerning connections between EFs and sport type (e.g. Krenn et al., 2018) as well as EFs and prior participation in different sport domains (Koch & Krenn, 2021) can, again, be interpreted as a link to the broad transfer hypothesis. However, other explanations for the explored differences may be valid as well. First, there could be a tendency that athletes who naturally exhibit higher EF levels are more likely to remain in open-skill sports because they are more successful in the specific sport right away. This might not be true for closed-skill sports, as high EF levels in closed-skill sports may not be as significant as in open-skill sports (Jacobson & Matthaeus, 2014). Therefore, athletes with higher EF levels could simply be more likely to reach a high level in strategic and open-skill sports compared to athletes in closed-skill sports, because EFs do not play such a crucial role in closed-skill sports (Krenn et al., 2018). Second, it was argued by Koch and Krenn (2021) that higher EFs in open skill athletes also result from extensively performing complex motor movements and a high prevalence of social interactions with team colleagues within their sport. These arguments provide an explanation for higher EF levels in open-skill compared to closed-skill athletes und do not necessarily support the broad transfer hypothesis.

1.3. Executive functions and playing position

Referring to team sports in general, there have only been a few studies in the past that performed analyses about differences in executive functions among different playing positions. However, Scharfen and Memmert (2019) address that, inter alia, knowledge about possible position-specific differences in cognitive functions could have a practical value to the enhancement of athletic development by integrating the cognitive component into practice using individual training programs. One study that was carried out in ice hockey by Lundgren et al. (2016) found significant differences in the Design Fluency Test, which measures inhibition, cognitive flexibility and decision making (Vestberg et al., 2012), between the center forward position and other positions in favor of center forwards. Lundgren et al. (2016) argued that players in the center forward position need to have higher levels of cognitive flexibility, split vision and decision-making skills than players in other positions, as they represent the link between defense and offense and need to make decisions rapidly. Concerning volleyball and playing position, Montuori et al. (2019) conducted a sport-specific switching task, which intended to measure cognitive flexibility, and distinguished between strikers, defenders, and mixed players. The strikers, who usually perform the attacks and try to hinder the attack from the opposing team, exhibited the fastest reaction times and lowest level of cognitive flexibility. The slowest reaction times were found in defending players. Mixed players, who are not as specialized as their colleagues and operate both as defending and attacking players, showed the best levels of cognitive flexibility, while strikers performed worst in the switching task. The authors named the high specialization of strikers and the varying tasks of mixed players as a possible explanation for the differences regarding cognitive flexibility. Another study from

Beavan et al. (2020) examined the effects of age, experience, and playing position on executive functions in soccer. Playing position did not seem to have a strong impact on executive functions. Nevertheless, the authors showed a significant interaction effect of age and position in the Determination Test, which measures reactive stress tolerance and reaction speed. Forward players in the study of Beavan et al. (2020) performed fewer correct responses and showed slower reaction times in the Determination Test compared to other players, and goalkeepers outperformed defenders in correct responses. Even though Vestberg et al. (2017) did not differentiate between playing positions in their study, they suggested that future research should carry out investigations about different levels of cognitive functions between playing positions. They argued that attackers in soccer have to be impulsive while defenders need to have a high level of inhibitory control and midfielders should have balanced EFs throughout the entire game. To sum up, research regarding position-specific differences in cognitive functions is sparse and yet indicates that possible EF differences based on playing position can exist. However, the mentioned studies measured different cognitive aspects (e.g. cognitive flexibility vs. reactive stress tolerance) and thus used different test batteries. Furthermore, Montuori et al. (2019) implemented a sport-specific task while other studies addressed cognitive abilities in sport-unspecific contexts, and they were all carried out in different team sports. Therefore, it is not really possible to compare these studies.

1.4. Cognitive functions of handball players

Team handball is an Olympic sport that is played in many countries all over the world and is especially popular in Europe. Handball is played seven against seven players (six field players and one goalkeeper) and the team which scores more goals in 60 minutes wins the game. The game is characterized by a high number of offense and defense actions; the ball possession changes generally after around 30 seconds (Karcher & Buchheit, 2014). Further, the game is typically marked by fast and dynamic movements and rapidly changing ball possessions. As handball has a very complex nature, it is not easy to define the significant factors that lead to high performance (Wagner et al., 2014). Several studies addressed physiological demands of handball players (e.g. Michalsik & Aagaard, 2014), including position-specific differences (e.g. Karcher & Buchheit, 2014). For example, handball players typically run, jump, make change of directions, perform one-on-one fights, catch and pass the ball, perform shots on the goal, and try to block the ball during the game (Wagner et al., 2014). The physical demands in team handball vary based on the playing position (Karcher & Buchheit, 2014). However, apart from physical components, handball players also need to be able to coordinate themselves and the ball at the same time, to sufficiently perceive the position of the ball and movement of their teammates, as well as the opposing players and must react to rapid changes throughout the entire game (Biscaia et al., 2021; Kiss & Balogh, 2019). Therefore, based on these demands and the fact that team handball is a dynamic open-skill sport (Holfelder, Klotzbier, Moritz, &

Schott, 2020), it can consequently be assumed that visuo-perceptual and cognitive functions, and more specifically EFs, could play an important role in the game.

The next paragraph will first focus on general cognitive functions in team handball, before then continuing with the evaluation of existing research about EFs and handball. At first, possible differences between cognitive functions of handball players and non-athletes will be discussed. After that, investigations about cognitive differences regarding team sports and differences between age groups in handball will be evaluated. In general, literature names attention, game intelligence (Wegner & Dawo, 2012), anticipation, decision making (Wagner et al., 2014), and court sense (Silva, 2006) as cognitive demands of handball players. When comparing general cognitive functions of team handball players with those of non-athletes, research, again, does not allow clear statements in either direction. Memmert, Simons, and Grimme (2009) did not detect any differences between expert handball players and non-athletes in basic attention processes such as maintaining or dividing attention, that were measured in sport-unspecific tasks. Thus, these results indicate no enhanced basic perceptual skills in expert handball players compared to non-athletes. Referring to chapter 1.2, this finding could be used as support for the narrow transfer hypothesis. However, other studies reported differences of cognitive functions between handball players and non-athletes in favor of handball players, which stands in line with specific findings of investigations about athletes and non-athletes that were discussed in the second to last chapter. Contrary to the results of Memmert et al. (2009), Zwierko, Florkiewicz, Fogtman, and Kszak-Krzyzanowksa (2014) discovered that the handball players of their study outperformed non-athletes in the ability to maintain attention in a visuomotor task. Furthermore, male handball players were found to exceed male non-athletes in cognitive functions such as spatial orientation and perceptual skills (Mitic, Stojiljkovic, Pavlovic, Gardasevic, & Jovic, 2019). Nevertheless, it can be criticized that these findings are not comparable to one another; the authors aimed at measuring different perceptual facets, used different test batteries, and the comparability of the handball players' league level of these studies can be doubted as well. In general, though, it can be assumed that cognitive abilities in open-skill sports are quite strongly pronounced. Ilic (2015) highlighted the importance of cognitive abilities for high sport performance in team sports and investigated male open-skill athletes. The author distinguished between male athletes, who played soccer, handball, basketball, and volleyball, and assessed their levels of cognitive skills such as perceptive and symbolic reasoning, and visual spatialization. Results revealed differences between the sports in favor of volleyball and basketball players, who seemed to exhibit higher levels of cognitive abilities. The author explained this by the nature of volleyball and basketball, which are played on a much smaller field and therefore require even more dynamics than soccer and handball. Thus, this finding could indicate that different team sports lead to different cognitive skill profiles in athletes, which can be interpreted as support for the broad transfer hypothesis. At last, differences between age groups of female handball players in cognitive functions such as perception, attention, and anticipation were investigated by Biscaia et al. (2021). Not surprisingly, the adult group (age 18 and above) outperformed the youngest group (age 11 and 12) in reaction time, anticipation and in the ability of reacting to several external stimuli that were presented at the same time. Therefore, these results indicate better anticipation and information-gathering abilities in the adult group compared to the youngest players.

Nevertheless, the previously mentioned publications solely investigated cognitive abilities and did not assess EFs. Altogether, literature addressing EFs in team handball is very limited. However, based on the previously mentioned findings about EFs in open-skill sports (e.g. Jacobson & Matthaeus, 2014; Krenn et al., 2018, Verburgh et al., 2014), and because handball as an open-skill sport is pervaded by permanently changing conditions, which force players to quickly adapt their behavior (Ilic, 2015), it can consequently be assumed that EFs play a certain role in team handball. Additionally, the importance of EFs in team handball was confirmed by some authors that discussed general psychological demands of handball players (Wagner et al., 2014; Silva, 2006). One of the few studies which examined EFs in team handball players was conducted by Heppe and Zentgraf (2019). In their study, male expert handball players showed improved inhibitory control at a sport-unspecific stop signal task compared to recreational athletes. Another study from Holfelder et al. (2020) confirmed previous findings about open and closed-skill sports. More specifically, handball players scored higher on a general EF measure, in this case the Trail-Walking-Test, compared to track-and-field athletes. Both of these findings are in line with the assumption that handball players display a certain level of EF. Moreover, when looking at the nature of team handball, it also seems natural that handball players frequently make use of their EFs during the game. For example, handball players need to be able to suppress irrelevant information (inhibition), such as the shouts of the opposing coach or the audience, and instead have to concentrate on the opponents and the free space to the opposing goal. In addition, a wing player has to use self-control when they receive the ball and is, according to a specific play, actually supposed to shoot in this attack situation, but aborts the attempt due to a very modest shooting angle, which minimalizes the chance of scoring a goal. Furthermore, goalkeepers are constantly exposed to fast and painful shots to their body but have to inhibit their pain and instead concentrate on the game if they want to continue playing. Working memory, on the other hand, is also needed by the goalkeeper who has to keep all shooting pictures and preferences of the opposing players in mind to successfully perform a save. All field players make use of their working memory when remembering the plays during the game and possibilities of how to play them or when memorizing typical attack habits of the opposing team and adapting their behavior according to this knowledge. Finally, a center back player needs to make use of their cognitive flexibility when the opposite team unexpectedly changes their defending formation and the center back player then has to switch to a different attacking strategy too. Furthermore, cognitive flexibility is essential in almost every part of team handball, as the conditions constantly change (e.g. attack and defense situation, decision of referees) and handball players constantly have to adapt and must deal with the new situation.

1.5. Executive functions and playing position in handball

Team handball consists of seven playing positions: center back (playmakers), left and right back, left and right wing, pivot, and goalkeeper. These positions differ from each other when it comes to ball contacts, body contact to other players and physiological demands (Karcher & Buchheit, 2014). Even though the literature addressing cognitive demands of the playing positions in handball is sparse, the author assumes, based on general knowledge about the strongly differing demands of the positions, that EF differences between the playing positions could exist. The next section of this chapter will first evaluate existing literature about cognitive functions and handball playing positions and will then go on to discuss the cognitive demands of each playing position. Based on these different cognitive demands, an attempt to form hypotheses about possible position-specific EF differences in team handball will be made.

To the author's knowledge, there is only one study that examined the phenomenon of cognitive demands of different playing positions in handball, yet not specifically the construct of EFs. Kiss & Balogh (2019) investigated decision-making skills, reactive stress tolerance, attention, and concentration of team handball players with the Vienna test system and performed some analyses about the differences due to playing position. In their study they discussed some interesting differences between the playing positions, even though these did not turn out to be statistically significant. The authors detected trends in reaction times (goalkeepers, playmakers and wings reacted faster than pivots and backs) when measuring concentration and trends in decision-making skills (playmakers reacted faster than all other positions when a high number of stimuli was presented while under pressure but also committed numerous mistakes). However, this study cannot be rated as highly important for this investigation, as the authors did not aim to assess EFs. Nevertheless, they discussed the cognitive demands of the playmaker (center back) position during the game as follows: *'Playmakers need to divide their attention continuously and possess a high concentration ability while maintaining attention, filtering disturbing stimuli and recognizing the essential elements'* (Kiss & Balogh, 2019, p. 739). Unfortunately, no further study addressed differences in cognitive abilities based on playing position in handball. In the next paragraphs, the playing positions will be thoroughly discussed, including possible cognitive demands of each position.

The center back position in team handball, synonymous with the playmaker position, usually organizes the game and is, in accordance with the coach and sometimes other back players, responsible for tactics. In addition, center back players have to make very rapid and a huge number of decisions and often have to change playing position when they run to the circle or change positions with a back player (Silva, 2006). Logically, they need to be able to quickly change perspectives and jump into different roles. It could thus be assumed that the playmaker position requires a high level of cognitive flexibility compared to other players who do not lead and organize the game but follow the instructions from their center back. Additionally, playmakers have to memorize a lot of information and keep several plays in mind, so that they are able to decide which play to use. This could be crucial when the defense, for instance, transforms their defense system and suddenly is playing offensively (further ahead from their goal) or defensively (closer to their goal and closer to the 6-meter-circle), contrary to what the attacking players or coach were previously expecting. In this case, the playmaker needs to remember previous situations and successful attacking strategies based on the new defense system. Consequently, it could be argued that playmakers need to have a higher level of working memory compared to other players. The following hypotheses about playmakers will be tested within the analyses:

H1: Playmakers exhibit higher levels of cognitive flexibility than other playing positions.

H1: Playmakers exhibit higher levels of working memory than other playing positions.

Both playmakers and back players exhibit the highest number of ball contacts and thus occupy a very responsible and leading position throughout the game (Karcher & Buchheit, 2014; Kromer, 2015). Because of this high number of ball contacts and their task to build up the game, back players have to make numerous decisions (Kolodziej, 2010). According to Brack (2002), back players must frequently take risky chances throughout the game, as they often perform the last shot on the goal or at least give the final pass to the next player, who conducts a goal attempt. Based on this assumption, left and right back players can maybe partly be compared with the striker position in volleyball. As discussed in chapter 1.3, Montuori et al. (2019) detected faster reaction times and lower levels of cognitive flexibility in strikers. This comparison could lead to the presumption that left and right back players could display lower cognitive flexibility levels compared to other players. On the other hand, when the back player has to rapidly decide whether to take their own chance of throwing a goal or to give the final pass to the next player instead, high levels of inhibition and cognitive flexibility are probably required in order to make the best choice for the team. Therefore, arguments for higher and lower levels of cognitive flexibility in left and right back players can be found, and it is unclear what to expect from the EF assessment. Consequently, no specific hypotheses were formed concerning EF differences between back players and other playing positions.

Wing players, however, need to be extremely quick and have to switch between defense and attack rapidly as they usually run most of the fast breaks (Kromer, 2015), cover the most meters during the game and thus display the highest aerobic capacity compared to all other positions (Sporis, Vuleta, Vuleta, & Dragan, 2010). On the one hand it could be argued that wings also need to be cognitively flexible when switching between defending and attacking positions. On the other hand, one could think that this switch between defense and attack is rather based on an automatism that was thoroughly established during training than on cognitive flexibility. Also, it could be argued that wing players need to show a high level of inhibition as they often have to suppress their original plan to run straight to the goal during a fast break when a defending player is suddenly blocking the way. In addition, wing players seem to also need a high level of inhibitory control when they receive the ball in a normal attack situation and must decide whether to make a throw on the goal or not. Kromer (2015) names being able to evaluate their chances of success and failure when receiving the ball during an attack situation a crucial skill for wing players. If the angle is too small and there is only a slim chance to score, wing players need to inhibit their impulse to make a shot and should rather pass the ball further on. Therefore, the author attempted to form the following hypothesis regarding wing players and their level of inhibitory control in comparison to other playing positions:

H1: Wing players exhibit higher levels of inhibitory control than other playing positions.

Players in the pivot position are usually standing close to the 6-metre-circle, surrounded by opposing players in an attacking situation and exhibit lower numbers of ball contacts compared to wings and backs (Kolodziej, 2010). Their job is it to open up spaces for their colleagues or to run to the free space themselves (Kromer, 2015). The pivot position is a very physically demanding position, as during a typical attack they constantly have to fight for a good position including pushing, being pushed, and blocking the way. Thus, pivot players exhibit the highest number of body contacts in a handball game (Karcher & Buchheit, 2014). On the other hand, they do not need to be as fast and as good at switching between defense and offense situations as wing players and have to make fewer decisions with the ball compared to their team colleagues. Pivot players, however, need to be able to anticipate movements and behaviors of their own teammates as well as those of opposing players. The pivot position probably requires a high level of inhibition, as they have to wait for the right moment to block defending players during an attacking situation in order to open up spaces for their own team or to run to the free space. Yet it seems unclear to the author whether pivot players actually exhibit a higher level of inhibition compared to their team colleagues due to the following reasons, which are also questioning the above-mentioned hypothesis of wing players' inhibition levels: First, it could be argued that all handball players need very high levels of inhibition and second, inhibition forms the basis of cognitive flexibility. Thus, players with high levels of cognitive flexibility (probably playmakers) naturally exhibit high levels of inhibition as well. Overall, one could conversely argue that the pivot position probably requires lower levels of EFs compared to other field players. This could be explained by the high physical demands and at the same time fewer numbers of decisions to make with the ball. More specifically, when a pivot player finally manages to catch a ball during an attack situation close to the 6-metre-circle, they usually immediately attempt to score a goal – there generally is no further pass and therefore no decision to make. Altogether, it is not possible to make a clear statement about the cognitive demands of pivot players. Thus, no hypothesis was formed regarding the EF levels of pivot players in contrast to other playing positions.

Compared to their teammates, completely different demands are placed on goalkeepers when it comes to success in a handball game. Even though a good performance of the goalkeeper is crucial for the team's success, only very few studies have been conducted about the essential demands of handball goalkeepers (Kajtna, Vuleta, Pori, Justin, & Pori, 2012; Karcher & Buchheit, 2014). While performing the slowest maximal running speed, goalkeepers have to react extremely rapidly when the ball is shot on the goal. Thus, fast reaction times (Sporis et al., 2010) on the one hand and experience and anticipation on the other hand seem to be essential demands of successful goalkeepers (Pori, Justin, Kajtna, & Pori, 2011). In the study of Kiss and Balogh (2019), goalkeepers rather reacted incorrectly to than omitted stimuli, which seems natural due to their tasks throughout the game. When an opposing player attempts to score a goal, there is no time to think about how to perform the save but they need to react extremely fast and automatically. Additionally, goalkeepers have to fulfill another important task: after a successful save, they frequently initiate the fast break when giving a long pass to the player furthest ahead or to the player closest to their own 6-meter-circle. Weber and Wegner (2016, S. 59) described the tasks of goalkeepers as follows: *'Fast actions like defense against shots and counter-attacks for goalkeepers [...] demand fast-working automatism and therefore low action-control'.* Kajtna et al. (2012) investigated the psychological factors of handball goalkeepers such as concentration, reaction times, and fluid intelligence, the latter of which can be equated with components of reasoning and problem-solving (Diamond, 2013) and is based on the three core EFs. Throughout the entire assessed variables, less successful goalkeepers exhibited a faster reaction time. The authors explained this effect by motivational reasons or the age distribution of their participants: Goalkeepers who had been rated more successful by experts were significantly older compared to those ranked as less successful. Furthermore, they mentioned that experience and tactics could possibly play a much more important role than reaction time in handball goalkeepers. Interestingly, neither of the aspects that were measured by Kajtna et al. (2012), including fluid intelligence, exhibited an influence on the success of the goalkeepers. Because of all the points mentioned, it could be argued that the handball goalkeeper's position does not require a high level of EFs in general. The fact that goalkeepers usually have to react automatically and do not have time to think would definitely support this reasoning. However, elite goalkeepers do a lot of shooting analysis about the opposing players before games and therefore have to keep a lot of information in mind during the game. Based on these thoroughly studied shooting habits, they adapt their behavior und saving strategy. Therefore, it could be argued that goalkeepers make use of their working memory quite a lot during the game. Even though literature about the psychological profiles of handball goalkeepers does not provide any clues about EF differences to other playing positions, the author formed the following hypothesis:

H1: Goalkeepers exhibit higher levels of working memory than other playing positions.

Moreover, after having discussed the cognitive demands of each playing position and the resulting hypotheses about possible EF differences, the question whether players with two playing positions display EF differences compared to specialized players with one playing position will be investigated. Based on the suggestion from Koch and Krenn (2021), that broader sports participation in youth connects with higher levels of EFs and the finding of Montuori et al. (2019), that not specialized mixed volleyball players exceed their team colleagues in cognitive flexibility measures, the author of this study hypothesizes higher levels of cognitive flexibility in players occupying two positions compared to highly specialized players.

H1: Players playing two positions exhibit higher levels of cognitive flexibility than players with one position.

Finally, a distinction between players who played center back as first or second position and players who did not play the center back position at all were carried out. This analysis was conducted because of the special role of playmakers throughout the game and the just mentioned hypothesis about players occupying two playing positions. Hence, the author hypothesizes higher levels of cognitive flexibility in players who play center back as first or second position.

H1: Players playing center back as first or second position exhibit higher levels of cognitive flexibility compared to non-center back players.

1.6. The Present Research

To sum up, in the past, only a few studies have dealt with differences in EFs due to playing position in team sports and research examining position-specific differences in cognitive functions in team handball is limited as well. Several arguments that were discussed in the previous paragraphs, however, lead to the presumption that differences in EFs with regard to playing position could exist. Thus, the aim of this study is to examine whether different playing positions exhibit different levels of EFs. For the subsequent analysis, there will be a distinction between five playing positions: center back, back (including left and right back), pivot, wing (including left and right wing), and goalkeeper position. The author hypothesizes higher levels of cognitive flexibility in center backs and higher levels of working memory in center back players and goalkeepers compared to other positions. In addition to that, the open question of whether wing players actually show higher levels of inhibitory control compared to their team colleagues will be investigated. Furthermore, analyses about differences between back players (center back und left and right back) and other field players (wing and pivot players) will be discussed. At last, analyses about possible differences between players who occupy one position compared to those playing at least two different positions will be explained closely.

2. Method

2.1. Participants

34 female and 48 male Austrian handball players, altogether 82 players, participated in this study. The age ranged from 14 to 29 years (M_{age} = 17.38 ± 2.58). The majority (n = 55) of the sample was attending school at the time of the assessment and thus stated mandatory school as highest educational level. 13 players had already graduated from high school, 11 participants were currently studying at university and only 3 players of the sample had already received their bachelor's degree at university. In order to ensure a certain performance level of the participants, only players of the youth national team, youth players who were attending a competitive handball sport school and players of the first league of Austria took part in this study. Concerning league level, 50 handball players stated to play competitions on an international level, 30 were playing nationally and only 2 players of the sample were playing on a regional level. The 50 players who competed on an international level were playing for the Austrian youth or adult national team when the study was conducted. Only 6 players disclosed to have been playing on a higher league level in the past than they were at the time of the assessment. The number of years the players had been playing handball ranged from 3 to 19 years (M_{years} = 8.76 ± 2.87), which is a consequence of the wide range of the participants' age. All players were asked to name their playing position on the handball field. Of all 82 participants, 25 declared themselves as left or right back players, 19 as wing players, 15 as center back players, 12 as pivot players and 11 as goalkeepers. 29 players reported to regularly play a second playing position, whereby the majority of them named their second position as the back position (left/right back n = 12, center back n = 11). Out of these 29 players with a second playing position, 15 players were switching between the center back and left/right back position, 12 players were instated on a back (center or left/right) and the wing position and only 2 players stated to be back and pivot players. No players switched between the wing and the pivot position and, naturally, no goalkeeper stated to play a second playing position. Regarding the playmaker position, 26 players played center back as first or second position, whereas 56 players did not play the playmaker position at all.

2.2. Materials

In this study, four neuropsychological tests that measure executive functions were performed. In order to measure inhibition and cognitive flexibility, the Design Fluency Test (Delis, Kaplan, & Kramer, 2001a) the modified flanker task (Eriksen & Eriksen, 1974) and a complex flanker task (Krenn et al., 2018) were carried out. Additionally, the complex flanker task was experimentally extended, and a second complex task was implemented. To measure working memory, a 2-back task was conducted in accordance with Krenn et al. (2018). Moreover, the coaches of the handball teams were asked to rate their players' game intelligence based on the idea of Vestberg et al. (2020).

2.2.1. Design Fluency Test

The Design Fluency test from the D-KEFS test battery is a paper-and-pencil test and consists of three different conditions. In every condition, participants are asked to draw as many different designs as possible in 60 seconds by connecting dots in a frame with four straight lines. Every straight drawn line has to touch at least one other line and the designs always have to differ from each other – it is not allowed to repeat patterns. The first condition only consists of black dots, the second and third condition of black and white dots. During the first condition, participants connect the black dots, whereas in the second conditions they should avoid the black dots and only connect white dots. In the third condition, participants have to switch between black and white dots when drawing the lines. Patterns that consist of more than four lines or violate the rules mentioned above in any other way are counted as wrong patterns. Even though Delis et al. (2001a) reported on acceptable validity of the Design Fluency, critique about insufficient reliability and the applicability of the test battery in sporting context was recently brought up (Finkenzeller et al., 2021). However, numerous studies in the past have assessed EFs by using the Design Fluency test and found interesting connections to performance variables (e.g. Koch & Krenn, 2021; Lundgren et al., 2016; Vestberg et al., 2012). From the Design Fluency test, several different variables can be obtained. Apart from the number of correctly drawn designs of each condition and the sum of those altogether, errors, a contrast measure and accuracy of drawn designs can be gained. Usually, the correct designs of each condition (Koch & Krenn, 2021) and/or the total correct score (e.g. Lundgren et al., 2016) are used for statistical analyses. Scholars are uncertain whether the obtained metrics of the Design fluency can clearly be assigned to one of the three core EFs. Swanson (2005) names condition 1 the basic task of the test battery and associates condition 2 with inhibition. Condition 3 and the Contrast Measure (difference between condition 3 and the first two conditions) are supposed to represent cognitive shifting (Swanson, 2005). However, Vestberg et al. (2012) explains that inhibitory control is needed in every condition, as participants have to avoid drawing the same pattern more than once. Furthermore, the sum of all correctly drawn designs is a combination of all the conditions and cannot clearly be assigned to one particular EF construct. Vestberg (2017) suggested that the total correct score possibly stands for higher executive functions. In this study, only four variables were obtained from the Design Fluency, namely the correct designs of condition 3 and the Contrast Measure (which are supposed to measure cognitive flexibility), the sum of total correct designs and, additionally, the accuracy of all drawn designs. The latter can, at this point, not even remotely be assigned to one of the core EFs. However, by using the accuracy measure, scores of participants who drew an impressive number and those who only drew a modest number of designs can be compared with one another. The following table presents the most important variables from the Design Fluency test. Because of the above-mentioned reasons, the author did not try to assign the variables to one of the core EFs. Raw scores of the test were scaled according to Delis et al. (2001a) so as to take the age of the participants into account.

Table 1: selected variables from the Design Fluency Test

variable	**explanation**
Correct Condition 3	scaled score of the correct designs of condition 3 (switching condition)
Total Correct Designs	scaled score of the sum of the correct designs from conditions 1, 2, and 3
Contrast Measure [3-(2+1)]	scaled score of the difference between the correct designs of condition 3 and sum of correct designs of condition 1 and 2
Accuracy	scaled score of the correct designs divided by the total attempted designs

2.2.2. Flanker task

In order to measure inhibition as well as cognitive flexibility, participants were asked to perform a modified Eriksen flanker task according to Krenn et al. (2018). First, the easy flanker task was executed to measure inhibition. In the easy flanker task, participants sit in front of a screen and are asked to press either M or C on the keyboard with their forefingers. They should react as correctly and as quickly as possible. Five white arrows appear on the screen and participants should press M on the keyboard when the center arrow points to the right and C when the arrow points to the left. Participants should only concentrate on the center arrow and ignore the other arrows. The four arrows next to the arrow in the middle either point to the same direction (congruent stimuli) or the opposite direction (incongruent stimuli) as the middle arrow. In total, 108 stimuli are shown in random order on the screen, 72 of them being congruent and 36 incongruent. Second, the complex part of the flanker task was carried out in order to measure cognitive flexibility. In the complex flanker task, the middle arrow is sometimes shown in green or red color. When the middle arrow appears to be green, participants should react the same way as in the previous condition, whereas when the middle arrow is shown in red, they should press the opposite key. For example, when the arrow in the middle is green and is directed to the left, participants should press C. When the arrow in the middle is red and pointed to the left, participants are supposed to press M. If the middle arrow is however pointing up- or downwards, participants should not react at all. The second part of the flanker task is supposed to measure cognitive shifting, as participants have to adapt their reaction depending on the color of the middle arrow. Especially when the middle arrow is shown in red, cognitive shifting is required because they have to switch their reaction to the opposite one. In the complex flanker task, altogether 108 stimuli were distributed on the screen (18 congruent, 18 incongruent stimuli, 18 red arrows, 18 green arrows, 36 neutral stimuli).

Moreover, another condition of the complex flanker task was established. This condition was specifically implemented for this study and has never been used before, therefore being completely experimental. The investigator introduced another condition with a new colored arrow and aimed to measure inhibition and cognitive flexibility. This condition only consisted of 96 stimuli. In addition to congruent, incongruent stimuli, red and green arrows (12 stimuli each) and 24 neutral stimuli, 24 blue arrows (12 congruent and 12 incongruent) were shown. Participants were asked to stick to the same rules as in the two previous conditions with one additional rule. When the arrow in the middle appeared in blue, participants should not react at all and thus were asked to suppress their reaction, just as when the arrow pointed up- or downwards. All stimuli in all conditions (easy and complex task) were shown for 1000ms on the screen. The following graphic distributes the stimuli of the three tasks including the correct (non-) responses.

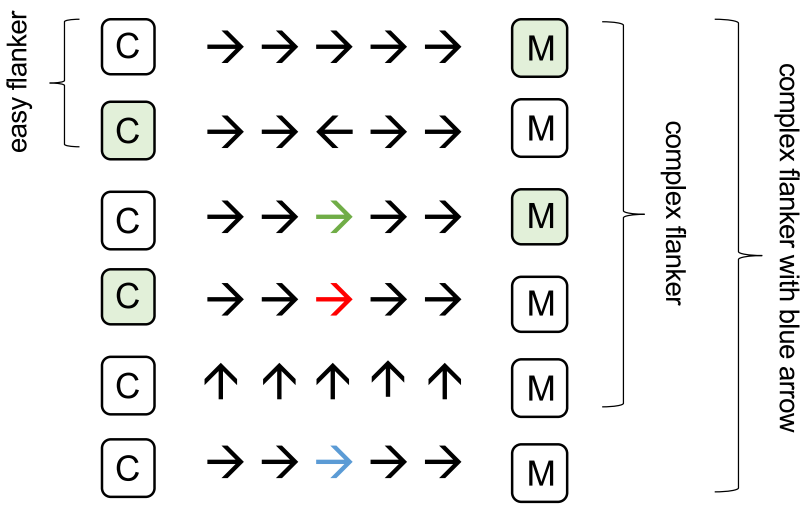

Figure 2: stimuli and correct (non-) responses of all flanker tasks (modified according to Krenn et al., 2018)

For all three conditions, variables such as errors, mean reaction time of correct responses, and differences between mean reaction times were obtained from the flanker task. Beside many other variables that can be gained from the flanker task, the variables in the following table are considered the most important ones (Krenn et al., 2018). The variables of the easy flanker task are supposed to measure inhibition. As regards the concept of cognitive shifting, the red arrow plays a vital role, which can be examined in the table below. In addition, errors on the blue arrow in the last flanker were included in the analysis, as this was the extra task in the experimental condition and the author aimed to investigate this newly implemented part. Because participants had to suppress their reaction when the blue arrow was distributed, the author hypothesized that errors on the blue arrow would represent the construct inhibition.

Table 2: selected variables of the flanker task

variables	flanker task	construct	explanation
inhib	easy flanker	inhibition	difference (%) of the mean reaction time (incongruent – congruent stimuli)
kon_reakzeit	easy flanker	*	mean reaction time (ms) of correct responses (congruent stimuli)
inkon_reakzeit	easy flanker	inhibition	mean reaction time (ms) of correct responses (incongruent stimuli)
inkon_fehler	easy flanker	inhibition	number of incorrect responses (incongruent stimuli)
komp_farbinkon _reakzeit	complex flanker	cognitive flexibility	mean reaction time (ms) of correct responses when the red arrow was distributed
komp_farbinkon _fehler	complex flanker	cognitive flexibility	number of incorrect responses when the red arrow was distributed
diff_meanRTrot_ kongreinfach	complex flanker	cognitive flexibility	difference (%) between the mean reaction time of stimuli showing the red arrow and the mean reaction time of correct responses of congruent (non-colored) stimuli
komp_farbinkon_ reakzeit_blau	complex flanker with blue arrow	cognitive flexibility	mean reaction time (ms) of correct responses when the red arrow was distributed during the complex flanker with blue arrow
komp_farbinkon_ fehler_blau	complex flanker with blue arrow	cognitive flexibility	number of incorrect responses when the red arrow was distributed during the complex flanker with blue arrow
diff_meanRTrot_ blau_ kongreinfach	complex flanker with blue arrow	cognitive flexibility	difference (%) between the mean reaction time of stimuli showing the red arrow and the mean reaction time of correct responses of congruent (non-colored) stimuli during the complex flanker with blue arrow
komp_blau_fehler	complex flanker with blue arrow	inhibition	number of incorrect responses when the blue arrow was distributed

** used to measure the variable inhib*

2.2.3. 2-back Task

N-back tasks measure working memory as well as sustained attention (Diamond, 2013). In this study, a 2-back task was performed analogue to Krenn, et al. (2018). Participants were watching a screen, on which numbers (1-6), geometric figures such as triangle and circle and dots on dices (1-6) appeared consecutively in a predetermined order. Participants were asked to press a key on the keyboard whenever the presented stimulus was identical to the one before the previous one. For example, when first a “3”, then a “5”, followed by a “3” appeared on the screen, participants were supposed to press the key, as the current stimulus was identical to the second to last one. Once again, stimuli of the 2-back task were presented for 1000ms. 48 stimuli of each category, altogether 144 stimuli, were shown to the participants and in 24 cases the current stimulus was identical to the second to last one. For a better understanding of the 2-back task, two examples are graphically displayed below.

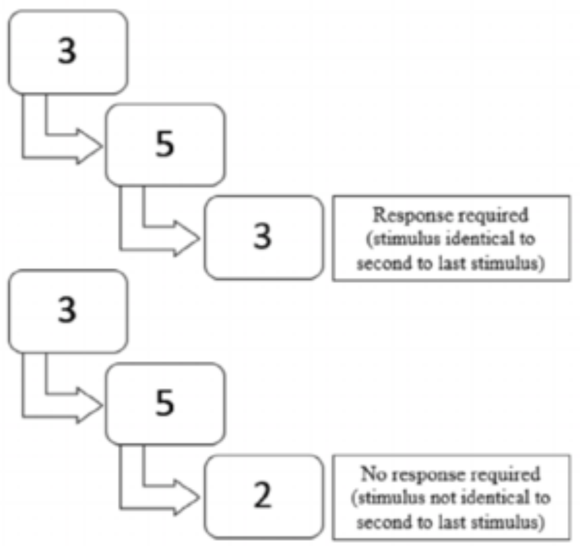

Figure 3: stimuli and responses of the 2-back task (Krenn et al., 2018)

From this test, correct responses, errors and difference between correct responses and errors were evaluated and are presented in the following table.

Table 3: selected variables of the 2-back task

variable	construct	explanation
richtige_nback	working memory	number of correct responses
falsche_nback	working memory	number of incorrect responses
diff_richtig_falsch_nback	working memory	difference between correct and incorrect responses

2.2.4. Coach-rated game intelligence

In addition to the EF measures, the coaches of the handball teams were confidentially asked to rate their players' game-intelligence on a 9-point scale, where the score of "1" means lowest and "9" means highest possible game intelligence. This measure is based on Vestberg et al. (2020), who found a moderate correlation between the Design Fluency score and the game-intelligence ratings of the soccer players' coaches in their study.

2.3. Procedure

First of all, the handball teams were acquired for this study via telephone calls. Most coaches received a fact sheet in advance, in which the construct of EFs, the theoretical background, the assessment as well as possible advantages for their participation were elucidated. The background and procedure of this study was previously discussed with the coaches of the respective teams. After the coaches had given their consent verbally, players were asked if they were willing to participate in this study. The assessments took place at the wardrobe or a room close to the participants' training facilities, the laboratory of the University of Vienna and in a quiet room in school when testing the group of players who were students at the competitive handball school. It was possible to test all players before a training session in order to avoid physical and mental fatigue when measuring the executive functions. For the assessment, subjects first had to give their consent in written form. In addition to that, participants were asked if they gave their permission about the transfer of the obtained data to their coach. Only if the handball player agreed to the transfer of the data, coaches received the results of the players after the assessment. A maximum of 6 participants performed the EF assessments simultaneously, so that participants had the possibility to ask questions if necessary and to ensure a quiet atmosphere throughout the assessment. Participants had previously been given codings to guarantee their pseudonymization. After having given their written consent, participants were instructed for the paper-and-pencil Design Fluency test and completed the three conditions. Then, each player was assigned to a laptop, on which the flanker and the 2-back task were conducted. Participants performed some practice trials before starting the actual flanker and 2-back task, where they received feedback on their reaction. After the EF assessment, players were asked to give information about sociodemographic variables, such as age and sex and sport-specific variables such as their current league level and their playing position. Furthermore, the participants had the chance to receive individual feedback of their results on the EF assessment by the investigator upon request. The assessments generally lasted between 30 and 45 minutes, depending on the number of the participants who were tested simultaneously. Additionally, coaches were asked to give a rating about their players' game-intelligence either prior to or after the EF assessment in written form or verbally to the investigator.

2.4. Statistical analysis

First of all, analyses about potential correlations between age and EF variables as well as differences in sex and league level were executed. Because the range of test subjects' age was quite large and it is known that age-related effects can occur (Krenn et al., 2018; Vestberg et al.; 2018), age was used as covariate in the following analyses. In order to detect position-specific differences in EF levels, ANCOVA analyses were carried out in this study. Only when age did not seem to have an effect at all on the variance of the variable, an ANOVA was further performed to see whether there was a significant difference without including age as a covariate. Prior to the ANCOVA and ANOVA analyses, *Levene's* - tests were carried out to check the homogeneity of variances. For the difference analyses, players were first divided in the following playing position groups: center back, back, pivot, wing, and goalkeeper. Second, center back players and left and right back players were united in one group and a distinction between the back position (including left, right back and center back), pivots, wing players, and goalkeepers was conducted. In case of statistically significant ANCOVAs or ANOVAs, post hoc tests were performed to examine which playing positions differ from one other. For this further analysis, the Bonferroni procedure was used in general, because it controls the Type I error and reduces the probability to find a difference by chance (Field, 2005). Only in some special cases when the ANCOVA showed a significant difference but the Bonferroni procedure did not, the LSD procedure was exceptionally performed, although this procedure does not take the Type I error into account and therefore must be interpreted with caution. Additionally, *t*-tests and Mann-Whitney tests were carried out to detect possible differences between players with only one playing position versus players with two playing positions and between back players versus pivots and wing players united in one group. Furthermore, it was analyzed via *t*-tests and Mann-Whitney tests whether players who switched between different back positions (center back and left or right back) and players who played at least one non-back position showed some differences in their EFs and if differences between players instated as playmakers as first or second position and players who did not play as center backs at all exist. For the sake of completeness, it should be mentioned that the significance level was set at 5% in all analyses and two-tailed significances were used in the entire study. All mentioned analyses were performed using the program IBM SPSS Statistics (version 28.0) and in accordance with Field's book (2005).

3. Results

3.1. Preliminary analyses

In order to get a better understanding of the assessed data, preliminary analyses were conducted and will be evaluated at this point before continuing with the main hypotheses testing. First, it will be discussed whether and to what extent sociodemographic and sport-related performance variables had an effect on the data. Therefore, the relationship between age, sex, years of playing, and league level and the possible link between those variables and the EF measures were analyzed. Second, the assessed EF measures will be evaluated more closely by examining their distribution and descriptive statistics. Eventually, correlation analyses within and between the different test batteries will be discussed.

3.1.1. Sociodemographic and sport-related performance variables

Because age did not follow a normal distribution, the Spearman correlation was used to detect possible correlations between age and EF test variables and age and other demographic variables. Naturally, age was significantly related to years of playing handball (r_s = .461, p < .001). Furthermore, when checking a possible connection between age and EF test variables, analyses revealed a significant correlation between age and the mean reaction time of stimuli showing the red arrow (r_s = .277, p = .012) and between age and errors on stimuli showing the blue arrow (r_s = -.243, p = .028). These correlations displayed that older athletes tended to react slower than younger athletes when the red arrow was distributed and made less mistakes on the blue arrow, though both connections were only modest. In addition, no significant age differences between the playing positions could be found. When it comes to sex, no significant differences concerning EF test variables were detected. Age, however, did play a certain role when distinguishing between male and female athletes. Even though the Mann-Whitney test did not detect a statistically significant difference between the age of males and females (p = .074) and the medians of male and female players were identical (*Mdn* = 17.00), some differences can be observed in the means and standard deviations with females being older compared to their fellow male subjects (females: M_{age} = 18.35 ± 3.53, males: M_{age} = 16.69 ± 1.24). Regarding the current league level, no significant differences were found in EF test variables between players who played nationally and those who played internationally. However, analyses did reveal some differences in EF test variables concerning the highest league level, although this variable only deviated slightly from the current league level (see 2.1). In this analysis concerning the league level, only the national and international league levels were included, as there were only two players who named the regional level as their current league and highest level. The t-test showed a significant difference in the Total Correct Designs of the Design Fluency ($t(78)$ = 2.581, p = .012, r = .28) in favor of players who had at least once played internationally (M = 13.93 ± 2.59) compared to players who stated the national league level as their highest (*M* = 12.25 ± 2.85). Further, a significant difference was detected in the errors on the blue flanker (*U* = 450.00, *p* = .014) via Mann-Whitney test. Players who disclosed the international level as their highest (*Mdn* = 1.00) committed significantly more mistakes than those with the national level as their highest level (*Mdn* = .50). Finally, it should be mentioned that there was a connection between sex and the current as well as the highest league level (all 82 players and the regional level were included at this point). A X^2 – test displayed significant associations between sex and the players' current league level (X^2(2, N = 82) = 16.408, $p < .001$) as well as between sex and highest league level (X^2(2, N = 82) = 16.373, $p < .001$). These connections can easily be recognized when looking at the frequencies of the players' sex and their competition leagues. Among the male athletes, 37 players currently played on an international, 9 on a national and 2 on a regional level, whereas only 13 female players competed on an international and 21 on a national level at the time of the assessment. There were only modest differences to the highest league level. 3 male and 3 female players, who currently competed nationally, had played on an international level in the past.

3.1.2. Descriptive statistics of test variables

All EF test variables were tested for normal distribution via Kolmogorov-Smirnov test and were graphically evaluated via histogram, Q-Q plot and boxplot. Some variables did not show a normal distribution at all and some variables just had a few statistical outliers that were consequently excluded. Those outliers were discovered graphically by boxplots and were not used in further analyses. The following variables exhibited statistical outliers: Scaled Score Accuracy ('1'), inhib ('31'), inkon_fehler ('13', '16', '17'), komp_farbinkon_fehler ('8', '9'), komp_farbinkon_fehler_blau ('4'), richtige_nback ('5'), diff_richtig_falsch_nback ('-19', '-17', '-13'). However, there were some variables that were not normally distributed in any manner: kon_reakzeit, inkon_reakzeit, komp_blau_fehler from the flanker task, and falsche_nback from the 2-back task. For these variables, non-parametric tests were used to analyze potential position-specific differences. However, in some cases ANCOVA analyses were still carried out when investigating these variables, even though normal distribution is a requirement for an ANCOVA analysis. Therefore, the results must be interpreted with caution. The following table shows the descriptive statistics of the EF test variables and of the coach-rated game intelligence.

Table 4: descriptive statistics of EF test variables and coach-rated game intelligence

descriptive statistics	test	n	min	max	M	SD
Correct Condition 3	Design Fluency	82	4	19	11.93	2.94
Total Correct Designs		82	5	19	13.38	2.80
Contrast Measure [3-(2+1)]		82	2	14	9.04	2.84
Accuracy		81	4	12	8.04	2.04
inhib	easy flanker	81	2.00	25.00	12.84	4.81
kon_reakzeit		82	370.00	649.00	451.15	58.85
inkon_reakzeit		82	423.00	761.00	509.24	62.07
inkon_fehler		79	0	12	4.05	2.48
komp_farbinkon_reakzeit	complex flanker	82	511.00	815.00	662.62	69.10
komp_farbinkon_fehler		80	0	6	2.03	1.53
diff_meanRTrot_kongreinfach		82	16.12	87.28	47.85	13.63
komp_farbinkon_reakzeit_blau		82	540.00	822.00	668.80	66.81
komp_farbinkon_fehler_blau		80	0	3	1.29	1.00
diff_meanRTrot_blau_kongreinfach		82	17.57	80.49	49.22	12.80
komp_blau_fehler		82	0	5.00	1.15	1.21
richtige_nback	2-back task	81	9	23	16.58	3.57
falsche_nback		82	1	29	7.60	5.71
diff_richtig_falsch_nback		78	-7	22	10.03	6.54
coach-rated game intelligence		82	1	9	5.27	1.35

3.1.3. Correlations within test variables

As already mentioned and discussed in chapter 2.2, four different neuropsychological tests were used in this study. These tests aim to assess widely the same EFs and yet are constructed very differently. For example, the Design Fluency test as a paper-and-pencil test and the complex flanker task, which is performed by using a computer program, both intend to measure facets of inhibition and cognitive flexibility. Therefore, it is important to check whether and to what extent the different test batteries are connected to each other. Furthermore, these correlation analyses help us to gain insight into the newly implemented flanker task with the blue arrow and probably make a contribution with respect to the validity of the new task. Hence, the next sections of this chapter will deal with correlation analyses within the test variables.

Correlations between coach-rated game intelligence and EF measures

To begin with, coach-rated game intelligence was only significantly related to the mean reaction time of stimuli showing the red arrow in the complex flanker with the blue arrow (r_p = - .265, p = .017). Thus, players who had received a higher game intelligence rating from their coaches generally committed less mistakes when the red arrow was distributed than players with a lower game intelligence score. Lower error rates on stimuli showing the red arrow implicate a greater switching ability. Correlation analyses did not reveal any other significant connections between EF test variables and coach-rated game intelligence. All results of the correlation analyses are presented in the table below. The only significant connection is highlighted with color.

Table 5: correlations between coach-rated game intelligence and EF measures

correlation			coach-rated game intelligence
Scaled Score Condition 3	Design Fluency	correlation coefficient	-.009
		Sign. (2-tailed)	.937
Scaled Score TCD		correlation coefficient	.072
		Sign. (2-tailed)	.520
Scaled Score [3-(2+1)]		correlation coefficient	-.056
		Sign. (2-tailed)	.618
Scaled Score Accuracy		correlation coefficient	-.110
		Sign. (2-tailed)	.328
inhib	easy flanker	correlation coefficient	.074
		Sign. (2-tailed)	.511
kon_reakzeit		correlation coefficient	-.043
		Sign. (2-tailed)	.702
inkon_reakzeit		correlation coefficient	-.006
		Sign. (2-tailed)	.960
inkon_fehler		correlation coefficient	-.079
		Sign. (2-tailed)	.490
komp_farbinkon_reakzeit	complex flanker	correlation coefficient	.049
		Sign. (2-tailed)	.661
komp_farbinkon_fehler		correlation coefficient	-.205
		Sign. (2-tailed)	.068
diff_meanRTrot_kongreinfach		correlation coefficient	.103
		Sign. (2-tailed)	.356
komp_farbinkon_reakzeit_blau		correlation coefficient	-.001
		Sign. (2-tailed)	.993
komp_farbinkon_fehler_blau		correlation coefficient	-.265*
		Sign. (2-tailed)	.017
diff_meanRTrot_blau_kongreinfach		correlation coefficient	.048
		Sign. (2-tailed)	.668
blau_komp_ fehler		correlation coefficient	.039
		Sign. (2-tailed)	.731
richtige_nback	2-back task	correlation coefficient	-.047
		Sign. (2-tailed)	.676
falsche_nback		correlation coefficient	.080
		Sign. (2-tailed)	.899
diff_richtig_falsch_nback		correlation coefficient	-.179
		Sign. (2-tailed)	.117

Correlations between variables within the Design Fluency test

As previously assumed, correlation analyses between different variables of the Design Fluency test exhibited numerous significant correlations, from small to large. Here, the Pearson-correlation was used for all variables. The following table shows the relationships between the variables of the Design Fluency test. All significant connections are highlighted with color.

Table 6: correlations within the variables of the Design Fluency test

correlation		Scaled Score Condition 3	Scaled Score TCD	Scaled Score [3-(2+1)]	Scaled Score Accuracy
Scaled Score Condition 3	correlation coefficient	1.000	.732**	.637**	.333**
	Sign. (2-tailed)	.	<.001	<.001	.002
Scaled Score TCD	correlation coefficient	.732**	1.000	-.042	.026
	Sign. (2-tailed)	<.001	.	.707	.818
Scaled Score [3-(2+1)]	correlation coefficient	.637**	-.042	1.000	.438**
	Sign. (2-tailed)	<.001	.707	.	<.001
Scaled Score Accuracy	correlation coefficient	.333**	.026	.438**	1.000
	Sign. (2-tailed)	.002	.818	<.001	.

Correlations between variables of the easy and complex flanker task

The easy and both complex flanker tasks (common complex flanker and complex flanker with blue arrow) naturally exhibited numerous significant, from small to large, relationships within its variables. As the mean reaction time of congruent (kon_reakzeit) and the mean reaction time of incongruent stimuli (inkon_reakzeit) from the easy flanker task and the errors on the blue arrow (blau_komp_fehler) from the last complex flanker task were not normally distributed, the Spearman-Rho correlation was used for correlation analyses concerning these variables. Apart from these, all variables showed a normal distribution and thus were tested via Pearson-correlation. The correlation coefficients and significances are presented in the following table. Significant correlations are again highlighted with color.

Table 7: correlations within the easy and complex flanker task

correlation		inhib	kon_ reakzeit	inkon_ reakzeit	inkon_fehler	komp_farbin kon_reakzeit	komp_farbin kon_fehler	diff_meanRT rot_kongrein fach	komp_farbin kon_reakzeit _blau	komp_farbin kon_fehler_ blau	diff_meanRT rot_blau_ kongreinfach	blau_komp_ fehler
inhib	correlation coefficient	1.000	-.377**	.043	.277*	-.311**	.222*	.134	-.306**	.228*	.164	.028
	Sign. (2-tailed)	.	<.001	.704	.014	.005	.049	.235	.005	.043	.143	.802
kon_reakzeit	correlation coefficient	-.377**	1.000	.849**	-.272*	.668**	-.178	-.459**	.661**	-.254*	-.534**	-.079
	Sign. (2-tailed)	<.001	.	<.001	.015	<.001	.113	<.001	<.001	.023	<.001	.482
inkon_reakzeit	correlation coefficient	.043	.849**	1.000	-.082	.579**	-.109	-.432**	.597**	-.202	-.502**	-.113
	Sign. (2-tailed)	.704	<.001	.	.470	<.001	.336	<.001	<.001	.073	<.001	.313
inkon_fehler	correlation coefficient	.277*	-.272*	-.082	1.000	-.264*	.494**	-.006	-.200	.337**	.102	.319**
	Sign. (2-tailed)	.014	.015	.470	.	.019	<.001	.958	.078	.003	.373	.004
komp_farbinkon_ reakzeit	correlation coefficient	-.311**	.668**	.579**	-.264*	1.000	-.311**	.228*	.831**	-.249*	-.016	-.236*
	Sign. (2-tailed)	.005	<.001	<.001	.019	.	.005	.04	<.001	.026	.886	.032
komp_farbinkon_ fehler	correlation coefficient	.222*	-.178	-.109	.494**	-.311**	1.000	-.251*	-.298**	.406**	-.245*	.239*
	Sign. (2-tailed)	.049	.113	.336	<.001	.005	.	.025	.007	<.001	.029	.033
diff_meanRTrot_ kongreinfach	correlation coefficient	.134	-.459**	-.432**	-.006	.228*	-.251*	1.000	-.026	.056	.757**	-.171
	Sign. (2-tailed)	.235	<.001	<.001	.958	.040	.025	.	.814	.619	<.001	.125
komp_farbinkon_ reakzeit_blau	correlation coefficient	-.306**	.661**	.597**	-.200	.831**	-.298**	-.026	1.000	-.268*	.131	.033
	Sign. (2-tailed)	.005	<.001	<.001	.078	<.001	.007	.814	.	.016	.242	.774
komp_farbinkon_ fehler_blau	correlation coefficient	.228*	-.254*	-.202	.337**	-.249*	.406**	.056	-.268*	1.000	.062	-.210
	Sign. (2-tailed)	.043	.023	.073	.003	.026	<.001	.619	.016	.	.585	.058
diff_meanRTrot_ blau_kongreinfac	correlation coefficient	.164	-.534**	-.502**	.102	-.016	-.245*	.757**	.131	.062	1.000	-.142
	Sign. (2-tailed)	.143	<.001	<.001	.373	.886	.029	<.001	.242	.585	.	.203
blau_komp_ fehler	correlation coefficient	.028	-.079	-.113	.319**	-.236*	.239*	-.171	.033	-.210	-.142	1.000
	Sign. (2-tailed)	.802	.482	.313	.004	.032	.033	.125	.774	.058	.203	.

Interestingly, the newly implemented variable (blau_komp_fehler) of the experimental complex flanker task was only significantly related to one other variable that is supposed to represent inhibition (inkon_fehler). However, analyses showed a significant small association to both switching variables (komp_farbinkon_reakzeit and komp_farbinkon_fehler) of the common complex flanker task.

Differences between variables of the complex flanker task and the new complex flanker task with the blue arrow

Furthermore, it was investigated if there was a significant difference between the crucial variables of the complex flanker and the newly administered complex flanker with the blue arrow. Logically, there is a strong relationship between the variables of both complex flanker parts. However, a dependent *t*-test was carried out to check possible differences between the mean reaction time of stimuli showing the red arrow (komp_farbinkon_reakzeit) from both complex flanker tasks and the errors on the red arrow (komp_farbinkon_fehler) from both complex flanker tasks. No significant difference was found between the mean reaction times when the red arrow was shown. The error rates of the two different complex flanker tasks when the red arrow was shown, however, significantly differed from each other ($t(78) = 4.15$, $p < .001$, $r = .43$). Participants tended to make fewer mistakes when the red arrow was distributed in the condition with the blue arrow (M = 1.29 ± 1.00) than without the blue arrow (M = 1.96 ± 1.49). Therefore, the blue arrow did not at all seem to complicate the task but rather to facilitate it. This can possibly be explained by learning effects from the previous complex flanker task.

Correlations between variables of the 2-back task

Concerning the 2-back task and the connections between its variables, the Pearson correlation was conducted for all analyses except for analyses regarding the number of false 2-backs. For this variable, the Spearman-Rho correlation was used. Correlation analyses displayed moderate to strong relationships, which was expected, particularly as the difference between correct and false 2-backs was calculated from the other variables.

Table 8: correlations within the variables of the 2-back task

correlation		richtige_ nback	falsche_ nback	diff_richtig_ falsch_nback
richtige_nback	correlation coefficient	1.000	-.509**	.836**
	Sign. (2-tailed)	.	<.001	<.001
falsche_nback	correlation coefficient	-.509**	1.000	-.840**
	Sign. (2-tailed)	<.001	.	<.001
diff_richtig_falsch _nback	correlation coefficient	.836**	-.840**	1.000
	Sign. (2-tailed)	<.001	<.001	.

Correlations between variables of the different test batteries

More interestingly however, correlation analyses between the variables of the different test batteries were performed. Several significant correlations among the variables of the Design Fluency and the 2-back task were detected. Correlation analysis revealed a significant relationship between correct designs of condition 3 and number of correct 2-backs ($r_p = .308$, $p = .005$) and the difference between correct and false 2-backs ($r_p = .339$, $p = .002$), between the total correct designs and number of correct 2-backs (r_p = .313, p = .004), number of false 2-backs (r_s = - .318, p = .004) and difference between correct and false 2-backs (r_p = .342, p = .002). Regarding the Design fluency and flanker task, just one small negative connection was found between total correct designs and the mean reaction time of stimuli showing the red arrow of the common complex flanker (r_p = - .228, p = .039). Finally, correlation analyses between variables of the flanker and the 2-back task exhibited small relationships between number of correct 2-backs and errors on the red arrow (r_p = - .262, p = .020), and between number of false 2-backs and number of incorrect responses when incongruent stimuli (easy flanker) were shown (r_s = .251, p = .026) and mistakes when the red arrow was distributed during the complex flanker with the blue arrow (r_s = .296, p = .008). Further, no significant correlations were found between EF test variables of different test batteries.

3.2. Hypothesis testing

Regarding possible position-specific differences in executive functions, the author had earlier hypothesized that playmakers could display a higher level of cognitive flexibility than players of other positions. Furthermore, it was previously discussed whether center back players and goalkeepers would exhibit higher levels of working memory and if wing players would show a higher ability of inhibition compared to their team colleagues. Moreover, analyses about EF differences between players occupying one or two playing positions were conducted. The author hypothesized higher levels of cognitive flexibility in players playing two different positions compared to very specialized players, who only play one position. Eventually, it was tested whether differences between players who stated to play the playmaker position as first or second position and players who did not play the center back position at all exist. Higher levels of cognitive flexibility were assumed in players who played center back as first or second position compared to players who were not instated as center backs. These hypotheses were tested below and will be evaluated in the following chapters.

3.3. Differences between playing positions

In the following paragraphs, analyses about possible EF differences between all playing positions will be discussed. Several distinctions between the playing positions were carried out and will be explained closely: Distinction between all playing positions, distinction between all playing positions when all back players (center back and left and right back) were merged, and distinction between different kinds of field players (backs vs. wings and pivots).

3.3.1. Distinction between all playing positions

First of all, difference tests were carried out in order to detect possible position-specific differences between all playing positions, namely: center back, back players, wings, pivots, and goalkeepers. The following table presents all test statistics regarding these analyses. Subsequently, further evaluations about the analyses will be given.

Table 9: analyses and test statistics regarding possible EF differences between all playing positions

differences between all playing positions	**test battery**	**statistical test**	**test statistics**
Correct Condition 3	Design Fluency	ANOVA	F(4, 77) = 2.21, *p* = .076, η² = .103
Total Correct Designs		ANOVA	F(4, 77) = 1.13, *p* = .348, η² = .055
Contrast Measure [3-(2+1)]		ANOVA	F(4, 77) = 2.66, *p* = .039, η² = .121
Accuracy		ANOVA	F(4, 76) = 1.05, *p* = .386, η² = .053
inhib	easy flanker	ANOVA*	F(4, 76) = 391, *p* = .814, η² = .020
kon_reakzeit		ANCOVA	F(4, 76) = .61, *p* = .659, η² = .031
inkon_reakzeit		ANCOVA	F(4, 76) = .66, *p* = .621, η² = .034
inkon_fehler		ANCOVA	F(4, 73) = 3.73, *p* = .008, η² = .170
komp_farbinkon_reakzeit	complex flanker	ANCOVA	F(4, 76) = 2.01, *p* = .102, η² = .095
komp_farbinkon_fehler		ANCOVA	F(4, 74) = 1.51, *p* = .207, η² = .076
diff_meanRTrot_kongreinfach		ANOVA*	F(4, 77) = 1.09, *p* = .368, η² = .057
komp_farbinkon_reakzeit_blau		ANCOVA	F(4, 76) = 2.57, *p* = .044, η² = .119
komp_farbinkon_fehler_blau		ANCOVA	F(4, 74) = 1.87, *p* = .126, η² = .092
diff_meanRTrot_blau_kongreinfach		ANCOVA	F(4, 76) = .99, *p* = .419, η² = .049
komp_blau_fehler		Kruskal-Wallis**	H (4) = 4.86, *p* = .302
richtige_nback	2-back task	ANOVA*	F(4, 76) = .99, *p* = .415, η² = .050
falsche_nback		Kruskal-Wallis**	H (4) = 4.12, *p* = .390
diff_richtig_falsch_nback		ANCOVA	F(4, 72) = 1.75, *p* = .149, η² = .088

**ANOVA was used instead of ANCOVA because age did not have an effect*

***Kruskal-Wallis test was used because age did not have an effect and variable was not normally distributed*

ANOVA analyses were performed when testing the variables of the Design Fluency test. Here, age was not used as a covariate, as the Design Fluency variables had previously been scaled and thus age had already been taken into account. Within this analysis, one significant difference was found concerning the variable Contrast Measure. The Bonferroni post hoc test revealed a significant difference (*p* = .024) between center backs (*M* = 10.13 ± 2.56) and goalkeepers (*M* = 6.27 ± 2.72). Playmakers exhibited the highest mean score of all positions. Wings, pivots, and back players, however, showed very similar mean scores on this variable between the scores of the center backs and goalkeepers. The following table shows the descriptive statistics of all positions.

Table 10: descriptive statistics of the variable Contrast Measure (Design Fluency test)

Contrast Measure [3-(2+1)]	descriptive statistics		
	n	M	SD
wing players	19	9.00	2.47
pivot players	12	9.33	3.05
left/right back players	25	9.28	2.86
center back players	15	10.13	2.56
goalkeepers	11	6.72	2.72
total	82	9.04	2.84

In order to analyze the variables of the easy and complex flanker task, ANCOVA analyses were conducted and age was used as covariate. Only when age did not have an influence at all, ANOVA analyses were performed. Within the easy flanker, a significant difference between the positions was revealed in the number of mistakes when incongruent stimuli were shown. Bonferroni post hoc tests showed significant differences between center back players (M = 2.07 ± 1.73) and wing players (M = 4.89 ± 3.05) with a significance of p = .006, and between center backs and left or right back players (M = 4.38 ± 2.42) with a significance of p = .041. Center back players committed the fewest mistakes out of all positions. Even though goalkeepers made quite a few mistakes as well (M = 4.60 ± 2.41), the difference between them and center back players was not significant according to the Bonferroni post hoc test (p = .062). The following table presents the descriptive statistics of this difference.

Table 11: descriptive statistics of errors on incongruent stimuli (easy flanker task)

inkon_fehler	descriptive statistics		
	n	M	SD
wing players	19	4.89	3.05
pivot players	12	3.92	1.62
left/right back players	24	4.38	2.24
center back players	14	2.07	1.73
goalkeepers	10	4.60	2.41
total	79	4.05	2.48

Eventually, a significant difference was found regarding the mean reaction time on stimuli showing the red arrow during the complex flanker task with the blue arrow. Although the ANCOVA analysis stated this difference to be significant, Bonferroni post hoc test did not show a significant difference between the playing positions. Because of that, an LSD post hoc test was additionally performed. The LSD post hoc test detected significant differences between wings (M = 695.58 ± 69.26) and left/right back players (M = 647.28 ± 59.28) with a significance of p = .023 and between wings and goalkeepers (M = 639.36 ± 82.51) with a significance of p

= .010. Thus, goalkeepers reacted faster than all other playing positions when the red arrow was distributed. However, in the following table one can also see that the reaction times of the goalkeepers showed a slightly larger deviation from the mean than the other groups.

Table 12: descriptive statistics of the mean reaction time on stimuli showing the red arrow (complex flanker with blue arrow)

komp_farbinkon_reakzeit_blau	**descriptive statistics**		
	n	**M**	**SD**
wing players	19	695.58	69.26
pivot players	12	683.83	56.39
left/right back players	25	647.28	59.28
center back players	15	680.33	58.75
goalkeepers	11	639.36	82.51
total	82	668.80	66.81

All other EF variables did not reveal any significant position-specific differences when distinguishing between center backs, left/right backs, pivots, wings, and goalkeepers. However, some interesting trends across the different test batteries were found, which did not turn out to be statistically significant. First, a trend regarding goalkeepers was detected. In the Design Fluency test, some slight but not significant mean differences were found concerning the correct designs in condition 3. Goalkeepers showed the lowest (M = 9.73 ± 2.76) and left and right back players (M = 12.60 ± 2.77) the highest mean score at this task. Further, as just explained in the previous paragraph, goalkeepers displayed a shorter reaction time on stimuli showing the red arrow (complex flanker with the blue arrow) compared to wing players. When looking at the reaction times on the red arrow though, the error rates on these stimuli should also be considered closely. Even though ANCOVA analyses did not reveal a significant difference in the error rates on the red arrow in the complex flanker task with the blue arrow, a quite interesting trend was observed. During the newly implemented complex flanker task, goalkeepers exhibited the highest error rates of all positions (M = 1.82 ± .87). To compare, the left/right back players exhibited the second highest mean number of errors (M = 1.38 ± .1.01), while center back players performed best (M = .933 ± .80). This effect, however, was above the significance level. Thus, in the condition with the blue arrow, goalkeepers reacted the fastest and committed the most mistakes when the red arrow was distributed. Another interesting trend concerned switching variables and center back players. In both complex flanker tasks, center back players made fewer mistakes on the red arrow than all other players, which was partly already mentioned. Just as in the newly implemented flanker, the difference between all positions concerning the false reactions on the red arrow in the common complex flanker was not significant but could be observed in the descriptive statistics. Center backs displayed the lowest (M = 1.33 ± 1.59) and left/right back players the highest error rate (M =

2.46 ± 1.61), followed by pivot players (*M* = 2.33 ± 1.37) and goalkeepers (*M* = 2.00 ± 1.05). In addition to that, the difference between the mean reaction time of the red arrow (complex flanker) and congruent stimuli (easy flanker) revealed very modest and not significant differences in favor of center backs. This variable indicates (in %) how much more time players needed to react when the red arrow was shown, compared to when the congruent stimulus in the easy flanker task was displayed. Center backs exhibited the lowest differences (*M* = 43.58 ± 13.57) of all positions and pivot (*M* = 51.38 ± 12.94) and wing players (*M* = 51.80 ± 14.08) the highest. One final trend in the 2-back task was observed regarding wing players. Even though none of these differences turned out to be statistically significant, wing players exceeded all other playing positions in two of the three variables that mainly represent the construct of working memory. Wing players detected the most correct 2-backs (*M* = 17.84 ± 3.86), goalkeepers performed second best (*M* = 16.64 ± 3.57), and pivots exhibited the lowest mean number of correct responses (*M* = 15.50 ± 3.80). And because wings also committed the fewest mistakes (*Mdn* = 5.00) after center backs (*Mdn* = 4.00), with only a very small and not significant difference, they exhibited the highest mean difference of correct and false responses on the 2-back task. Although this difference was, again, not significant, some differences can definitely be observed in the descriptive statistics of this variable. Wings displayed the highest mean score (*M* = 13.33 ± 4.73) of all positions, followed by goalkeepers (*M* = 9.18 ± 7.41), and pivots disclosed the lowest mean difference (*M* = 7.83 ± 8.11).

3.3.2. Distinction between backs, wings, pivots, and goalkeepers

In this section, position-specific differences between all back players (including center back and left/right back), pivots, wings, and goalkeepers will be presented. As closely discussed in chapter 1.5, center backs and back players fulfill very similar tasks throughout a handball game, as they are responsible for building up the game and occupy very important leading positions. Thus, putting together all back players (center back and left/right back) seems reasonable because of the similar position-specific demands, even though that means creating unequal sample sizes at the same time. The test statistics of the analyses are, again, first presented in the table below before continuing with further explanation.

Table 13: analyses and test statistics regarding possible EF differences between backs, wings, pivots, and goalkeepers

differences between backs, wings, pivots, and goalkeepers	test battery	statistical test	test statistics
Correct Condition 3	Design Fluency	ANOVA	F(3, 78) = 2.89, *p* = .041, η² = .100
Total Correct Designs		ANOVA	F(3, 78) = .93, *p* = .428, η² = .034
Contrast Measure [3-(2+1)]		ANOVA	F(3, 78) = 3.25, *p* = .026, η² = .111
Accuracy		ANOVA	F(3, 77) = .56, *p* = .645, η² = .021
inhib	easy flanker	ANOVA*	F(3, 77) = .45, *p* = .717, η² = .017
kon_reakzeit		ANCOVA	F(3, 77) = .49, *p* = .686, η² = .019
inkon_reakzeit		ANCOVA	F(3, 77) = .596, *p* = .619, η² = .023
inkon_fehler		ANCOVA	F(3, 74) = 1.85, *p* = .145, η² = .070
komp_farbinkon_reakzeit	complex flanker	ANCOVA	F(3, 77) = 2.51, *p* = .065, η² = .089
komp_farbinkon_fehler		ANCOVA	F(3, 75) = .31, *p* = .819, η² = .012
diff_meanRTrot_kongreinfach		ANOVA*	F(3, 78) = 1.36, *p* = .262, η² = .049
komp_farbinkon_reakzeit_blau		ANCOVA	F(3, 77) = 2.57, *p* = .060, η² = .091
komp_farbinkon_fehler_blau		ANCOVA	F(3, 75) = 1.84, *p* = .148, η² = .068
diff_meanRTrot_blau_kongreinfach		ANCOVA	F(3, 77) = 1.29, *p* = .282, η² = .048
komp_blau_fehler		Kruskal-Wallis**	H (3) = 3.80, *p* = .284
richtige_nback	2-back task	ANOVA*	F(3, 77) = 1.26, *p* = .293, η² = .047
falsche_nback		Kruskal-Wallis**	H (3) = 2.76, *p* = .431
diff_richtig_falsch_nback		ANCOVA	F(3, 73) = 2.31, *p* = .083, η² = 087.

**ANOVA was used instead of ANCOVA because age did not have an effect*

***Kruskal-Wallis test was used because age did not have an effect and variable was not normally distributed*

ANOVA analysis revealed two significant differences, both concerning variables of the Design Fluency test. First, a position-specific difference was found when analyzing the variable Contrast Measure. This was not unexpected, as the very same difference was detected when distinguishing between all playing positions. Once again, the Bonferroni post hoc test revealed a significant difference (*p* = .016) between goalkeepers (*M* = 6.27 ± 2.72) and back players, who performed best (*M* = 9.60 ± 2.75). The following table basically reflects the same difference as in the previous paragraph, except that, at this point, all back players (left/right back and center backs) were merged into one group.

Table 14: descriptive statistics of the variable Contrast Measure (Design Fluency test)

Contrast Measure [3-(2+1)] descriptive statistics	n	M	SD
wing players	19	9.00	2.47
pivot players	12	9.33	3.05
back players	40	9.60	2.75
goalkeepers	11	6.72	2.72
total	82	9.04	2.84

Second, a trend, which was observed when distinguishing between all playing positions but which was not significant (see 3.3.1), turned out to be statistically relevant when center back and back players were merged. The variable correct designs in condition 3 exhibited position-specific differences according to ANOVA analysis. The Bonferroni post hoc test reported a significant difference (p = .040) between goalkeepers, who drew the fewest correct designs (M = 9.73 ± 2.76) at this switching task, and back players, who performed best (M = 12.43 ± 3.00). The means of all playing positions are presented in the following table. The observable difference between wing players and goalkeepers was not statistically significant (p = .087).

Table 15: descriptive statistics of the variable Correct Condition 3 (Design Fluency test)

Correct Conditon 3	**descriptive statistics**		
	n	**M**	**SD**
wing players	19	12.42	2.67
pivot players	12	11.50	2.58
back players	40	12.43	3.00
goalkeepers	11	9.73	2.76
total	82	11.93	2.94

3.3.3. Distinction between back players and pivots/wings

In this part of the chapter, differences between general types of field players will be evaluated. For that, the field players were divided in back players, who build up and organize the game (center back, left and right back), and non-back players (pivots and wings), who usually have fewer ball contacts and mainly follow the playmaking of the back players. Goalkeepers were not included in this analysis, as, at this point, it was the intention of the author to investigate possible EF differences in field players. The table below displays all test statistics within this analysis. Significant differences are highlighted with color.

Table 16: analyses and test statistics regarding possible EF differences between backs and pivots/wings

difference between back players and wings/pivots	test battery	statistical test	test statistics
Correct Condition 3	Design Fluency	independent *t*-test	*t*(69) = -.53, *p* = .599, r = .06
Total Correct Designs		independent *t*-test	*t*(69) = .18, *p* = .876, r = .02
Contrast Measure [3-(2+1)]		independent *t*-test	*t*(69) = -.73, *p* = .470, r = .09
Accuracy		independent *t*-test	*t*(69) = -1.18, *p* = .244, r = .14
inhib	easy flanker	independent *t*-test	*t*(68) = .74, *p* = .462, r = .09
kon_reakzeit		Mann-Whitney test*	*U* = 594.00, *p* = .767
inkon_reakzeit		Mann-Whitney test*	*U* = 549.00, *p* = . 410
inkon_fehler		independent *t*-test	*t*(67) = 1.66, *p* = .101, r = .20
komp_farbinkon_reakzeit	complex flanker	independent *t*-test	*t*(69) = 2.45, *p* = .017, r = .28
komp_farbinkon_fehler		independent *t*-test	*t*(68) = .02, *p* = .986, r = .02
diff_meanRTrot_kongreinfach		independent *t*-test	*t*(69) = 1.99, *p* = .050, r = .23
komp_farbinkon_reakzeit_blau		independent *t*-test	*t*(69) = 2.11, *p* = .038, r = .25
komp_farbinkon_fehler_blau		independent *t*-test	*t*(67) = -.02, *p* = 983., r < .01
diff_meanRTrot_blau_kongreinfach		independent *t*-test	*t*(69) = 1.68, *p* = .097, r = .20
komp_blau_fehler		Mann-Whitney test*	*U* = 550.50, *p* = . 395
richtige_nback	2-back task	independent *t*-test	*t*(68) = .75, *p* = .455, r = .09
falsche_nback		Mann-Whitney test*	*U* = 508.00, *p* = . 192
diff_richtig_falsch_nback		independent *t*-test	*t*(65) = 1.11, *p* = .271, r = .14
**Mann-Whitney test was used because variable was not normally distributed*			

The Design Fluency test and the 2-back task did not reveal any statistically significant differences between backs and other field players. However, in both complex flanker tasks the mean reaction time on stimuli showing the red arrow significantly differed from each other. These switching variables of both complex flanker tasks showed that back players reacted significantly faster than pivots and wings combined. Interestingly, the errors when the red arrow was distributed did not show any differences at all between backs and other field players. Thus, even though back players reacted faster than other field players, they did not exhibit a higher number, but basically the same number of mistakes as other field players. The following tables present the mean reaction times of back players versus pivots and wings combined.

Table 17: descriptive statistics of mean reaction times when the red arrow was distributed (common complex flanker task)

komp_farbinkon_reakzeit	descriptive statistics		
	n	M	SD
back players	40	649.33	64.20
wings/pivots	31	687.29	65.68
total	71	665.90	67.12

Table 18: descriptive statistics of mean reaction times when the red arrow was distributed (complex flanker task with blue arrow)

komp_farbinkon_reakzeit _blau	descriptive statistics		
	n	M	SD
back players	40	659.68	60.53
wings/pivots	31	691.03	63.86
total	71	673.37	63.52

Apart from the mean reaction time on the red arrow, no significant differences between back players and other field positions were detected. One variable of the complex flanker task, however, did show a slight difference between backs and the other field positions, but this difference was minimally above the significance level. Back players showed a lower difference (*M* = 45.14 ± 13.77) than other field players (*M* = 51.64 ± 13.43) when the mean reaction time of congruent stimuli during the easy flanker was subtracted from the mean reaction time of stimuli showing the red arrow. This means that back players needed less extra time to react to the red arrow in contrast to the easiest task (congruent stimuli during the easy flanker) compared to pivot and wing players combined. This difference, however, was just minimally not statistically significant. The same variable from the complex flanker task with the blue arrow naturally showed a very similar picture, yet was not statistically significant either. Back players exhibited a slightly higher mean difference compared to the common complex flanker (*M* = 47.37 ± 11.74), but still a lower level compared to the other field positions (*M* = 52.56 ± 14.26).

3.4. Distinction between playing one or two playing position(s)

A further distinction between players who stated to only play one playing position compared to players who mentioned to regularly play at least two different playing positions was conducted and will be presented in this section. As already discussed in chapter 2.1, 29 players regularly played two different playing positions. More than half of these players (n = 15) were switching between two back positions (center back and left/right back position), all other players were instated as wing and back player (n = 12) or as pivot and back player (n = 2). As goalkeepers do not play a second position, they were not included in this analysis at first. The following table contains all performed analyses and test statistics regarding players with one or two positions.

Table 19: analyses and test statistics regarding possible EF differences between players with one or two positions

difference between players with one and two position(s) (without goalkeepers)	test battery	statistical test	test statistics
Correct Condition 3	Design Fluency	independent *t*-test	*t*(69) = .06, *p* = .949, r < .01
Total Correct Designs		independent *t*-test	*t*(69) = .09, *p* = .924, r = .01
Contrast Measure [3-(2+1)]		independent *t*-test	*t*(69) = .31, *p* = .761, r = .04
Accuracy		independent *t*-test	*t*(69) = .35, *p* = .727, r = .04
inhib	easy flanker	independent *t*-test	*t*(68) = .51, *p* = .613, r = .06
kon_reakzeit		Mann-Whitney test*	*U* = 601.00, *p* = . 925
inkon_reakzeit		Mann-Whitney test*	*U* = 603.50, *p* = . 949
inkon_fehler		independent *t*-test	*t*(67) = .80, *p* = .428, r = .10
komp_farbinkon_reakzeit	complex flanker	independent *t*-test	*t*(69) = .29, *p* = .775, r = .03
komp_farbinkon_fehler		independent *t*-test	*t*(68) = 2.17, *p* = .034, r = .25
diff_meanRTrot_kongreinfach		independent *t*-test	*t*(69) = .58, *p* = .564, r = .07
komp_farbinkon_reakzeit_blau		independent *t*-test	*t*(69) = -.33, *p* = .742, r = .04
komp_farbinkon_fehler_blau		independent *t*-test	*t*(66.99) = 1.53, *p* = .131, r = .18
diff_meanRTrot_blau_kongreinfach		independent *t*-test	*t*(69) = -.06, *p* = .953, r < .01
komp_blau_fehler		Mann-Whitney test*	*U* = 531.50, *p* = . 338
richtige_nback	2-back task	independent *t*-test	*t*(66.66) = -.50, *p* = .621, r = .06
falsche_nback		Mann-Whitney test*	*U* = 562.00, *p* = .581
diff_richtig_falsch_nback		independent *t*-test	*t*(65) = -.64, *p* = .526, r = .08

**Mann-Whitney test was used because variable was not normally distributed*

The Design Fluency test and 2-back task did not show any differences between players with one and those with two playing positions. On the contrary, analyses regarding the complex flanker task revealed one significant difference. This difference, again, concerned the red arrow and thus cognitive shifting. In the common complex flanker task, players who mentioned to regularly play two playing positions exhibited lower error rates when the red arrow was distributed compared to players with one playing position. The table below shows the mean number of errors when the red arrow was distributed.

Table 20: descriptive statistics of errors when the red arrow was distributed (complex flanker)

komp_farbinkon_fehler	descriptive statistics		
	n	M	SD
1 position	41	2.37	1.56
2 positions	29	1.55	1.53
total	70*	2.03	1.59

** without goalkeepers*

The same trend can be observed in the complex flanker with the blue arrow concerning the errors on the red arrow, but the difference did not turn out to be significant. Players with one position still performed worse (*M* = 1.35 ± 1.10) than players with two positions (*M* = 1.00 ± .80).

However, when the goalkeepers, who all only played one position, were included in the analysis, even both variables (errors on the red arrow) of the two complex flanker tasks showed a significant difference between players with one and two positions (common complex flanker: $t(78) = 2.14$, $p = .036$, $r = .24$, complex flanker with blue arrow: $t(71.83) = 2.14$, $p = .036$, $r = .24$). The mean error rates of this significant difference are presented in the tables below.

Table 21: descriptive statistics of errors when the red arrow was distributed (complex flanker)

komp_farbinkon_fehler	**descriptive statistics**		
	n	**M**	**SD**
1 position	51	2.29	1.47
2 positions	29	1.55	1.53
total	80*	2.03	1.53

** including goalkeepers*

Table 22: descriptive statistics of errors when the red arrow was distributed (complex flanker with the blue arrow)

komp_farbinkon_fehler_blau	**descriptive statistics**		
	n	**M**	**SD**
1 position	51	1.45	1.06
2 positions	29	1.00	1.06
total	80*	1.23	1.00

** including goalkeepers*

3.4.1. Differences between players with two positions

Out of the 29 players who stated to regularly play two different playing positions, 15 players switched between two back positions and 14 players either switched between back and wing or between back and pivot position. All back positions fulfill very similar tasks during the game compared to wing and pivot players, who are involved in a different way. This raises the question of whether differences between EFs of players with two back positions and players with one back and one other position exist. Although the group of players with two positions in this study was quite modest with n = 29, a distinction and analysis between pure back players and players with one non-back position was still experimentally conducted. Because of this very small sample size, the following analyses must be interpreted with caution. The table below presents the conducted test statistics regarding these analyses. The significant differences are highlighted with color.

Table 23: analyses and test statistics regarding possible EF differences between players with two back positions and players with one non-back position

differences between players with two playing positions	test battery	statistical test	test statistics
Correct Condition 3	Design Fluency	independent *t*-test	*t*(27) = -.21, *p* = .837, r = .04
Total Correct Designs		independent *t*-test	*t*(27) = -.55, *p* =.292 , r = .11
Contrast Measure [3-(2+1)]		independent *t*-test	*t*(27) = .13, *p* = .896, r = .03
Accuracy		independent *t*-test	*t*(27) = -.83, *p* = .417, r = .16
inhib	easy flanker	independent *t*-test	*t*(26) = -3.57, *p* < .001, r = .57
kon_reakzeit		Mann-Whitney test*	*U* = 51.00, *p* = .018
inkon_reakzeit		Mann-Whitney test*	*U* = 86.00, *p* = .425
inkon_fehler		independent *t*-test	*t*(27) = -2.74, *p* = .011, r = .47
komp_farbinkon_reakzeit	complex flanker	independent *t*-test	*t*(27) = 1.28, *p* = .211, r = .24
komp_farbinkon_fehler		independent *t*-test	*t*(27) = -.31, *p* = .762, r = 06.
diff_meanRTrot_kongreinfach		independent *t*-test	*t*(27) = -1.59, *p* = .124, r = .29
komp_farbinkon_reakzeit_blau		independent *t*-test	*t*(21.94) = 2.01, *p* = .057, r = .39
komp_farbinkon_fehler_blau		independent *t*-test	*t*(27) = -.93, *p* = .363, r = .18
diff_meanRTrot_blau_kongreinfach		independent *t*-test	*t*(27) = -1.26, *p* = .108, r = .24
komp_blau_fehler		Mann-Whitney test*	*U* = 105.00, *p* = 1.00
richtige_nback	2-back task	independent *t*-test	*t*(26) = -3.05, *p* =.005 , r = .51
falsche_nback		Mann-Whitney test*	*U* = 97.00, *p* = .747
diff_richtig_falsch_nback		independent *t*-test	*t*(25) = -1.82, *p* = .081, r = .34

**Mann-Whitney test was used because variable was not normally distributed*

No differences were found regarding the variables of the Design Fluency test. In the easy flanker though, some significant differences were detected. To begin with, a quite strong significant difference was identified concerning the difference of mean reaction time between incongruent and congruent stimuli. The smaller the difference is, the less extra time participants needed to react to incongruent stimuli compared to the congruent stimuli. The *t*-test showed that players who were instated on two back positions needed less extra time to adapt compared to the players on back and wing or back and pivot positions. This effect was statistically significant. The descriptive statistics can be found in the following table.

Table 24: descriptive statistics of difference (%) of the mean reaction time between incongruent and congruent stimuli (easy flanker)

inhib	descriptive statistics		
	n	M	SD
B/B*	15	9.53	4.36
B/W or B/P*	13	15.46	4.41
total	28	12.29	5.25

* B = back player (center back & left/right back)

* W = wing player

* P = pivot player

Second, the analysis revealed a significant difference in the mean reaction time of congruent stimuli in the easy flanker. Here, a Mann-Whitney test was conducted because the variable (kon_reakzeit) was not normally distributed (see 3.1.2). Players, who switched between two different back positions, generally reacted slower in comparison to players who switched between a back and another position (wing or pivot). Thus, concerning the easiest task of the flanker task, players with two positions, who were instated on back and a non-back position (wing or pivot), performed significantly better than pure back players. Interestingly, on the one hand, players with at least one non-back position tended to react faster not only when congruent stimuli were shown compared to pure back players but also when incongruent stimuli were distributed (*M* = 502.21 ± 59.67 vs. pure back players *M* = 523.47 ± 68.48). This difference was not statistically significant. On the other hand, however, the difference of mean reaction time between congruent and incongruent stimuli (inhib), which was just discussed in the previous paragraph, elucidated that pure back players needed less extra time to adapt when the incongruent stimuli were shown compared to players who played one back and one non-back position (wing or pivot). The medians of the mean reaction times of congruent stimuli are presented in the table below.

Table 25: descriptive statistics of mean reaction time when congruent stimuli were distributed (easy flanker)

kon_reakzeit	**descriptive statistics**	
	n	**Mdn**
B/B*	15	466.00
B/W or B/P*	14	418.00
total	29	429.00

* B = back player (center back & left/right back)
* W = wing player
* P = pivot player

Moreover, a significant difference was detected in the number of errors on incongruent stimuli during the easy flanker task. Players with at least one non-back position committed significantly more mistakes when the direction of the arrows on either side deviated from the center arrow in contrast to pure back players. This significant difference can be observed in the following table.

Table 26: descriptive statistics of the errors on incongruent stimuli (easy flanker)

inkon_fehler	**descriptive statistics**		
	n	**M**	**SD**
B/B*	15	2.47	2.26
B/W or B/P*	14	5.00	2.71
total	29	3.69	2.77

* B = back player (center back & left/right back)

* W = wing player

* P = pivot player

Within this distinction, no variable of the complex flanker tasks exhibited a significant difference. In any case, for the first time within the analyses, a significant difference was found concerning a variable of the 2-back task, implicating differences in working memory. Players with one back and one non-back position (wing or pivot) detected significantly more correct 2-backs than pure back players with two back positions. The descriptive statistics are presented in the table below.

Table 27: descriptive statistics of the number of correct responses (2-back task)

richtige_nback	**descriptive statistics**		
	n	**M**	**SD**
B/B*	15	15.40	2.67
B/W or B/P*	13	18.46	2.63
total	28	16.82	3.03

* B = back player (center back & left/right back)

* W = wing player

* P = pivot player

Furthermore, another difference, though not statistically significant, was found regarding the difference between correct and false 2-backs within the distinction between players who played two positions. Players with at least one non-back position, who also detected significantly more correct 2-backs, exhibited a higher mean difference (M = 12.77 ± 5.04) than pure back players (M = 8.93 ± 5.86). A high difference in this case means having found a great number of correct 2-backs while only committing few mistakes on the n-back task. However, this difference was minimally above the significance level.

3.5. Differences between playmakers and non-playmakers

This chapter will evaluate possible EF differences between players who played center back as first or second position and players who did not play center back at all. Apart from 15 players, who stated to mainly play as center backs (first position), 11 further players occupied the playmaker position as second position. Because, naturally, no goalkeeper was instated as playmaker (nor any other field position), they were not included in this analysis. Thus, 26 players were assigned to the playmaker position and 45 players to the non-playmaker position. Even though this distinction creates very unequal sample sizes, analyses were nevertheless conducted but must be discussed cautiously. The following table shows all analyses regarding possible EF differences between playmakers as first or second position and non-playmakers. The significant differences are, again, highlighted with color.

Table 28: analyses and test statistics regarding possible EF differences between playmakers and non-playmakers

differences between playmakers and non-playmakers (without goalkeepers)	**test battery**	**statistical test**	**test statistics**
Correct Condition 3	Design Fluency	independent *t*-test	$t(69) = .35$, $p = .728$, r = .04
Total Correct Designs		independent *t*-test	$t(69) = -.05$, $p = .962$, r < .01
Contrast Measure [3-(2+1)]		independent *t*-test	$t(69) = .52$, $p = .604$, r = .06
Accuracy		independent *t*-test	$t(69) = -.10$, $p = .922$, r = .01
inhib	easy flanker	independent *t*-test	$t(68) = -.10$, $p = .321$, r = .01
kon_reakzeit		Mann-Whitney test*	$U = 545.00$, $p = .637$
inkon_reakzeit		Mann-Whitney test*	$U = 560.00$, $p = .765$
inkon_fehler		independent *t*-test	$t(67) = -2.31$, $p = .024$, r = .27
komp_farbinkon_reakzeit	complex flanker	independent *t*-test	$t(69) = -.66$, $p = .514$, r = .08
komp_farbinkon_fehler		independent *t*-test	$t(68) = -2.20$, $p = .031$, r = .26
diff_meanRTrot_kongreinfach		independent *t*-test	$t(69) = -1.34$, $p = .185$, r = .16
komp_farbinkon_reakzeit_blau		independent *t*-test	$t(69) = .17$, $p = .864$, r = .02
komp_farbinkon_fehler_blau		independent *t*-test	$t(61.82) = -1.40$, $p = .166$, r = .18
diff_meanRTrot_blau_kongreinfach		independent *t*-test	$t(69) = -.44$, $p = .661$, r = .05
komp_blau_fehler		Mann-Whitney test*	$U = 575.00$, $p = .905$
richtige_nback	2-back task	independent *t*-test	$t(68) = -.54$, $p = .594$, r = .07
falsche_nback		Mann-Whitney test*	$U = 477.00$, $p = .173$
diff_richtig_falsch_nback		independent *t*-test	$t(65) = -.67$, $p = .507$, r = .08

**Mann-Whitney test was used because variable was not normally distributed*

T-tests revealed significant differences between playmakers (as first or second position) and non-playmakers regarding the flanker task. The finding of chapter 3.3.1, when differences between all positions were carried out, was confirmed in this analysis. Playmakers (as first or second position) committed significantly fewer mistakes on incongruent stimuli than players who were not playing center back. This difference can be found in the following table.

Table 29: descriptive statistics of the number of incorrect responses when incongruent stimuli were shown (easy flanker)

inkon_fehler	**descriptive statistics**		
	n	**M**	**SD**
center back players	25	3.08	2.79
non-center back players	44	4.48	2.17
total	69	3.97	2.49

The reaction times when the red arrow was distributed during the complex flanker task did not differ from each other between playmakers and non-playmakers. However, analysis detected a significant difference between playmakers and non-playmakers concerning errors on the red arrow, in favor of center back players. The direction of this difference was confirmed by the same variable (errors on red arrow) in the complex flanker task with the blue arrow, albeit this difference was above the significance level. Playmakers also outperformed non-playmakers in errors on the red arrow in the complex flanker with the blue arrow. The table below shows the descriptive error rates of the statistically significant difference.

Table 30: descriptive statistics of errors on the red arrow (complex flanker)

komp_farbinkon_fehler	**descriptive statistics**		
	n	**M**	**SD**
center back players	26	1.50	1.66
non-center back players	44	2.34	1.48
total	70	2.03	1.59

No further significant differences were found regarding EF variables and playmakers (first or second position) and non-playmakers. Both significant results that were just discussed regarding errors on incongruent stimuli and errors on the red arrow revealed also significant differences between playmakers and non-playmakers when goalkeepers were included in the analyses (inkon_fehler: $t(77) = - 2.45$, $p = .017$, r = 27, komp_farbinkon_fehler: $t(78) = - 2.19$, p = 032, r = .24).

3.6. Game-intelligence and playing position

Finally, an ANCOVA analysis about possible position-specific differences concerning coach-rated game intelligence was carried out. The table below shows the analyses and test statistics that were performed.

Table 31: analyses and test statistics regarding coach-rated game intelligence and position-specific differences

differences between all playing positions	**statistical test**	**test statistics**
coach-rated game intelligence	ANCOVA	F(4, 76) = 1.13, p = .348, η² = .056

differences between backs, wings, pivots, and goalkeepers	**statistical test**	**test statistics**
coach-rated game intelligence	ANCOVA	F(3, 77) = .71, p = .547, η² = .027

differences between backs and wings/pivots	**statistical test**	**test statistics**
coach-rated game intelligence	independent t-test	t(69) = -.63, p = .531, r = .08

differences between players with one or two playing position(s) (without goalkeepers)	**statistical test**	**test statistics**
coach-rated game intelligence	independent t-test	t(69) = -1.04, p = .301, r = .12

differences between players with two playing positions	**statistical test**	**test statistics**
coach-rated game intelligence	independent t-test	t(27) = - .101, p = .920, r = .02

differences between playmakers and non-playmakers (without goalkeepers)	**statistical test**	**test statistics**
coach-rated game intelligence	independent t-test	t(69) = 1.82, p = .073, r = .21

The analysis showed no statistically significant difference when distinguishing between all playing positions. However, some trends can be observed in the descriptive statistics between the various positions. Playmakers received the highest mean rating (*M* = 5.80 ± 1.01), followed by wing players (*M* = 5.34 ± .78) and pivot players were rated worst (*M* = 4.92 ± 1.88). And even though no distinction between the positions (e.g. one vs. two positions) revealed a significant difference regarding game intelligence, one further trend concerning this matter will be discussed here. In the previous chapter, players playing center back as first or second position and players who were not playing center back at all were distinguished. A *t*-test did not reveal a significant difference between those two groups, yet some differences can be observed in the descriptive statistics. Players playing center back as first or second position were rated higher (*M* = 5.65 ± .94) from their coaches than players who did not play the playmaker position (*M* = 5.08 ± 1.45).

3.7. Summary of significant differences

Here is a short summary of the statistically significant differences that were detected throughout the analyses.

Table 32: summary of statistically significant results

distinction	test variable	test	test statistics	direction of the difference	possible interpretation
differences between all playing positions	Contrast Measure (Design Fluency)	ANOVA	$F(4, 77) = 2.66$, $p = .039$, $\eta^2 = .121$	Bonferroni: center backs showed higher means compared to goalkeepers ($p = .024$)	higher cognitive flexibility in center back players compared to goalkeepers
differences between all playing positions	inkon_fehler (easy flanker)	ANCOVA	$F(4, 73) = 3.73$, $p = .008$, $\eta^2 = .170$	Bonferroni: center backs showed lower error rates compared to wings, and left/right back players ($p = .006$)	higher inhibition in center back players compared to wings and left/right back players
differences between all playing positions	komp_farbinkon_reakzeit (complex flanker)	ANCOVA	$F(4, 76) = 2.57$, $p = .044$, $\eta^2 = .119$	Bonferroni: no differences, LSD: wings reacted slower compared to goalkeepers ($p = .010$) and left/right back players ($p = .023$).	higher cognitive flexibility in left/right backs and goalkeepers compared to wing players
distinction between backs, wings, pivots, and goalkeepers	Contrast Measure (Design Fluency)	ANOVA	$F(3, 78) = 3.25$, $p = .026$, $\eta^2 = .111$	Bonferroni: back players (center back & left/right back) scored higher compared to goalkeepers ($p = .016$)	higher cognitive flexibility in back players compared to goalkeepers
distinction between backs, wings, pivots, and goalkeepers	Correct Designs Condition 3 (Design Fluency)	ANOVA	$F(3, 78) = 2.89$, $p = .041$, $\eta^2 = .100$	Bonferroni: back players scored higher than goalkeepers ($p = .040$)	higher cognitive flexibility in back players compared to goalkeepers
distinction between back players and pivots/wings	komp_farbinkon_reakzeit (complex flanker)	independent *t*-test	$t(69) = 2.45$, $p = .017$, $r = .28$	back players reacted faster compared to pivots/wings	higher cognitive flexibility in back players compared to pivots/wings
distinction between back players and pivots/wings	komp_farbinkon_reakzeit_blau (complex flanker with blue arrow)	independent *t*-test	$t(69) = 2.11$, $p = .038$, $r = .25$	back players reacted faster compared to pivots/wings	higher cognitive flexibility in back players compared to pivots/wings
one vs. two playing positions (without goalkeepers)	komp_farbinkon_fehler (complex flanker)	independent *t*-test	$t(68) = 2.17$, $p = .034$, $r = .25$	players with two positions committed fewer mistakes than players with one position	higher cognitive flexibility in players with two positions compared to players with one position

distinction	test variable	test	test statistics	direction of the difference	possible interpretation
one vs. two playing positions (with goalkeepers)	komp_farbinkon_fehler (complex flanker)	independent *t*-test	*t*(78) = 2.14, *p* = .036, *r* = .24	players with two positions committed fewer mistakes than players with one position	higher cognitive flexibility in players with two positions compared to players with one position
one vs. two playing positions (with goalkeepers)	komp_farbinkon_fehler_blau (complex flanker with blue arrow)	independent *t*-test	*t*(71.83) = 2.14, *p* = .036, *r* = .24	players with two positions committed fewer mistakes than players with one position	higher cognitive flexibility in players with two positions compared to players with one position
back/back players vs. wing/back or pivot/back players	inhib (easy flanker)	independent *t*-test	*t*(26) = 3.57, *p* < .001, *r* =.57	players with two back positions exhibited a smaller difference between the mean reaction time of incongruent and congruent stimuli than players with one non-back position	higher inhibition in players with two back positions compared to players with one non-back position
back/back players vs. wing/back or pivot/back players	kon_reakzeit (easy flanker)	Mann-Whitney Test	*U* = 51.00, *p* = .018	players with one non-back position reacted faster to congruent stimuli than players with two back positions	no possible interpretation based on this variable; variable was used to measure inhib (see 2.2.2)
back/back players vs. wing/back or pivot/back players	inkon_fehler (easy flanker)	independent *t*-test	*t*(27) = 2.74, *p* = .011, *r* = .47	players with two back positions committed fewer mistakes on incongruent stimuli compared to players who played one non-back position	higher inhibition in players with two back positions compared to players with one non-back position
back/back players vs. wing/back or pivot/back players	richtige n_back (2-back task)	independent *t*-test	*t*(26) = 3.05, *p* = .005, *r* = .51	players with one non-back position detected more correct 2-backs than players with two back positions	higher working memory in players with one non-back position compared to players with two back positions
differences between playmakers and non-playmakers	inkon_fehler (easy flanker)	independent *t*-test	*t*(67) = - 2.31, *p* = .024, *r* = .27	playmakers (first or second position) committed less mistakes on incongruent stimuli thank non-playmakers	higher inhibition in playmakers (first or second position) than non-playmakers
differences between playmakers and non-playmakers	komp_farbinkon_fehler (comlex flanker)	independent *t*-test	*t*(68) = - 2.20, *p* = .031, *r* = .26	playmakers (first or second position) committed less mistakes on red arrows thank non-playmakers	higher cognitive flexibility in playmakers (first or second position) than non-playmakers

4. Discussion of results

In this investigation, position-specific differences in executive functions of team handball players were examined. To the author's knowledge, this was the first study to address possible EF differences in team handball according to playing position. Previous research about position-specific differences in other team sports (e.g. Montuori, et al., 2019; Lungdren et al, 2016) indicated that EF differences according to playing position exist. Based on knowledge about position-specific demands of team handball players (e.g. Karcher & Buchheit, 2014; Kromer, 2015; Kolodziej, 2010), it was earlier hypothesized that playmakers would exceed other players in levels of cognitive flexibility and working memory, that goalkeepers would also perform very well in terms of working memory measures and that wing players could, and this was proposed very tentatively, exhibit higher levels of inhibitory control compared to their team colleagues.

To begin with, the results of EF levels of center back players will be discussed. Center back players outperformed all other playing positions in inhibitory control, according to one variable of the easy flanker task, namely errors on incongruent stimuli. Post hoc tests revealed significant better scores in playmakers compared to wing players and left and right back players. This finding was confirmed when all playmakers, including players who stated to play center back as second position, were set in contrast to non-playmakers. Players with the center back as first or second position significantly outscored their team colleagues in errors on incongruent stimuli. Thus, even though this effect concerning inhibition was only observable in one variable, it can be assumed that center back players exhibit higher levels of inhibitory control than other players. Moreover, one variable of the Design Fluency test (Contrast Measure) exhibited significant higher scores within center back players than goalkeepers, who performed worst out of all positions. As this variable intends to measure cognitive shifting, playmakers showed higher levels of cognitive flexibility compared to goalkeepers. In addition, several trends that were not statistically significant were detected regarding playmakers and variables representing cognitive flexibility. Center backs committed fewer mistakes when the red arrow was distributed compared to all other positions and needed the least extra time to adapt when the red arrow was shown in relation to congruent stimuli. Hence, playmakers only made very few mistakes and adapted more quickly when the task got more complex. Once again, one of the trends just mentioned was confirmed by a statistically significant difference when the distinction between playmakers as first or second position and non-playmakers was conducted: Players who played center back as first or second position outscored their counterparts in errors on the red arrow. Altogether, these findings suggest higher levels of cognitive flexibility in center back players and stand in line with the results of Lundgren et al. (2016), who found higher EFs in ice hockey center forwards than players in other positions. With respect to variables representing the concept of working memory, no differences between center backs and other players were detected. The hypothesis about playmakers and higher levels of cognitive flexibility and working memory compared to their team colleagues could thus only be partially verified: Playmakers showed better skills in terms of cognitive flexibility and inhibitory control. Thus, center back players seem to have a better ability to suppress irrelevant or unwanted stimuli or thoughts, and switch between perspectives so as to quickly adapt to new and unexpected situations. At this point, the question whether the playmaker position enhances such skills throughout practice or if coaches rather select players for the center back position who display high EF levels remains unanswered.

Regarding left and right back players, results did not show a clear picture about their EF levels. Left and right back players exhibited, along with goalkeepers, the fastest reaction time when the red arrow in the complex flanker task with the blue arrow was distributed. However, this finding was accompanied by a high error rate on the red arrow from left and right back players. Thus, this fast reaction and high error rate at the same time do not necessarily indicate higher levels of cognitive shifting in left and right back players. On the other hand, a non-significant but observable trend in the Design Fluency task (Condition 3) showed that left and right back players outperformed their team colleagues, especially goalkeepers, in drawn designs. As this variable is supposed to represent cognitive shifting (Swanson, 2005), this finding implicates higher cognitive flexibility in left and right back players. Hence, based on these indistinct results, it is at this point not possible to make a conclusive statement about cognitive flexibility levels of left and right back players. However, the fast reaction times and high error rate on the complex part of the flanker task support the finding of Montuori et al. (2019), who found that strikers in volleyball show very fast reactions and lower cognitive flexibility levels. Nevertheless, it is not clear whether left and right back players in team handball can be compared with strikes in volleyball, as back players are responsible for building up the game too and do not only perform final shots on the goal. As already mentioned in previous chapters, playmakers and back players do not fulfill the exact same tasks throughout the game, but partly very similar or at least strongly overlapping ones. Thus, analyses concerning differences between back players, including playmakers and left and right backs, and other playing positions were conducted and revealed nearly the same findings when distinguishing between all playing positions. Back players (center, left and right back) scored significantly higher on Design Fluency tasks (Contrast Measure and Condition 3) than goalkeepers. These findings indicate that back players (playmaker and left and right back) exhibit higher levels of cognitive flexibility than goalkeepers. Furthermore, when distinguishing only between field players (goalkeepers excluded), back players outscored wings and pivots in reaction time when the red arrow was distributed in both complex flanker tasks. Errors on the red arrow did not show any differences within this distinction. Thus, back players were able to react faster at a complex task with no increase of incorrect answers. However, it should be mentioned at this point that center back players exhibited very low error rates and mediocre reaction times and that left and right back players displayed fast reaction times and high error rates. These results should therefore be interpreted with caution. One more trend was detected in the complex flanker task among backs versus wings and pivots. Although not statistically significant, back players (playmaker and left and right backs) exceeded wing and pivot players in the difference in reaction time between the most complex (red arrow) and easiest part of the flanker task (congruent stimuli). Collectively, these results indicate higher levels of cognitive flexibility in back players (centers and left and right backs) than other field players (wings and pivots). However, referring to the unclear results regarding solely left and right back players and cognitive flexibility, the relationship between back players and cognitive shifting needs further investigation.

Goalkeepers, on the other hand, were outperformed by center backs (Contrast Measure) and back players (Correct Designs Condition 3) in Design Fluency variables that are supposed to measure cognitive shifting. Even though goalkeepers exhibited the fastest reaction time on the red arrow out of all playing positions, this effect was, again, accompanied by the highest (complex flanker with blue arrow) and the second highest (complex flanker) error rates. Thus, goalkeepers reacted very fast in this complex task, albeit not as correctly as other players. This finding can easily be explained by their demands throughout the game. Goalkeepers need to react extremely fast when attempting to perform a save or when initiating the fast break and must not hesitate while doing so. Therefore, it seems quite obvious that goalkeepers reacted immensely fast on the complex task, which simultaneously increased the risk of reacting incorrectly, rather than reacting a little slower and reducing error probability. This finding coincides with previous results of Kiss and Balogh (2019), who found that goalkeepers rather reacted incorrectly than omitted stimuli. To sum up, the results regarding the red arrow provide an ambiguous picture about cognitive flexibility levels of goalkeepers, but can easily be explained by the sport-specific demands of handball goalkeepers. Nevertheless, together with the result of the Design Fluency, the measures implicate lower levels of cognitive flexibility in goalkeepers compared to back players. Once again, no significant differences were found concerning working memory variables. Hence, according to past research and findings of this study, it can be argued that handball goalkeepers do not have the time to think about what to do but have to react instinctively and do not make use of their EFs as much as field players do. However, one could also argue that the goalkeepers of this study, who were mainly youth goalkeepers, are probably not yet performing a lot of shooting analysis in comparison to professional adult goalkeepers. In contrast, youth goalkeepers usually focus on goalkeepers' technique in practice and do not start with regular shooting analysis until adulthood and solely when playing at an elite league level. This argument provides another possible explanation for not having found very high working memory levels in goalkeepers. Yet, either way, the previously mentioned hypothesis about higher levels of working memory in goalkeepers could definitely not be confirmed. Altogether, according to the results of this study, EFs do not seem to play a vital role in handball goalkeepers, which stands in line with the findings of Kajtna et al. (2012) and Weber & Wegner (2016).

Moreover, the hypothesis about wing players exhibiting higher levels of inhibition than other positions was not only not supported, but refuted. Wing players displayed the most mistakes on incongruent stimuli during the easy flanker task and analysis showed a significant difference between wings and playmakers. This indicates lower levels of inhibitory control in wing players than in center backs and contradicts the assumption that wing players require a high level of inhibition when deciding whether to make an attempt on the goal or not. The only clue about the level of cognitive flexibility in wing players was provided in the complex flanker task. Wing players needed significantly more time to react when the red arrow was distributed than goalkeepers and left and right back players. Nonetheless, their error rate on the red arrow was second best after the playmakers in both complex flanker tasks. Thus, the assessments of cognitive flexibility in this study did not point in either direction regarding wing players. Interestingly, however, wing players exceeded all other positions in the working memory task, though analyses did not reveal significant differences. Based on the sport-specific demands of wing players, it seems unclear why they should exhibit higher working memory levels than other handball players. However, as this effect was not significant, it should not be considered as that important.

Pivot players did not display any significant differences in their EF levels compared to their team colleagues. Throughout the analysis, it is noteworthy that pivot players tended to achieve average scores in a lot of assessments and did not stand out in either direction. As already mentioned, when distinguishing between back players and other field players, including wings and pivots, back players showed faster reaction times than wings and pivots and faster adaptation to more complex tasks. Even though this could be interpreted as lower levels of cognitive flexibility in pivots, these findings probably reveal more about back players than solely pivot players, as none of these differences were detected when all positions were distinguished regarding pivot players. Altogether, this study did not provide indications about the cognitive profile of pivot players in relation to other positions.

Previously, the hypothesis was proposed that players occupying two playing positions would exhibit higher levels of cognitive flexibility. The results of this investigation support this hypothesis. Players with two playing positions outperformed their specialized colleagues in both complex flanker tasks: They committed fewer mistakes on the red arrow while reacting just as fast on this task as players with one position. Therefore, not so specialized players who were instated on two playing positions, exceeded highly specialized players in the ability to switch between perspectives and adapt quickly to new and complex tasks. These findings are consistent with past research (Koch & Krenn, 2021; Montuori et al., 2019). The latter detected higher cognitive flexibility in mixed volleyball players compared to specialized strikers and defenders. Thus, this result can be interpreted as higher cognitive flexibility levels in players with two positions compared to players with one position.

The following discussion about the results within the group of players with two playing positions should be considered quite critically due to the small sample size of players playing two positions. Players with two back positions scored higher on two inhibition measures in the easy flanker task than players with one non-back position. Thus, it can be presumed that pure back players (speaking for those who played two back positions) showed higher inhibitory control than players who played one back and one non-back position (wing or pivot). Nonetheless, players with one non-back position outscored players with two back positions in the 2-back task in correct answers. As nearly all of the players with one back and one non-back position were instated as wing players as first or second position, this result can perhaps be associated with the previous, though not significant, result that wing players outscored other players in the working memory task. Altogether, this indicates higher levels of inhibitory control in players with two back positions and higher levels of working memory in players with one back and one non-back position. By assuming that a broader experience in sports leads to higher EFs (Koch & Krenn, 2021), one could argue that players with one back and one non-back position would exhibit higher EFs compared to pure back players. This can only partially be confirmed. However, these findings support previous results of the current study that back players in general seem to display higher levels of inhibitory control compared to other players.

Finally, results regarding coach-rated game intelligence should be evaluated. No significant differences according to playing position were found in game intelligence. Only when distinguishing between players in the center back as first or second position against non-center back players, a not significant trend was revealed. Playmakers received a higher rating of game intelligence compared to non-playmakers. Furthermore, game-intelligence was only correlated to the reaction time to the red arrow in the complex flanker task with the blue arrow and no other variables. On the one hand, this stands in line with Lundgren et al. (2016), who did not detect connections between game intelligence and Design Fluency measures. On the other hand, the results of this study contradict the findings of Vestberg et al. (2020), who found a correlation between game intelligence and the Design Fluency test. It is possible that the way of collecting the data of game intelligence in this study was not appropriate and could be improved. Closer critique about the assessment of game intelligence in this investigation will be given in the next chapter.

Altogether, the results of this investigation have revealed some new insights into EFs of handball players according to playing position. It seems that EF differences based on playing position in handball could exist to some extent. Playmakers seem to have superior EF levels compared to other playing positions, in terms of cognitive flexibility and inhibitory control. Back players also showed higher cognitive flexibility levels, albeit this being only substantially the case when they were merged with center back players. Generally, goalkeepers reacted very fast on complex tasks but displayed lower cognitive flexibility levels and wing players exhibited lower inhibitory control in contrast to playmakers. Furthermore, players instated on two different playing positions seemed to exceed specialized players with one playing position when it came to cognitive flexibility. These results indicate that players of different playing positions, particularly playmakers, exhibit different cognitive skill profiles.

The background and reasons for these possible differences, however, cannot be clarified at this point. Following the broad transfer hypothesis, which suggests that extensive experience in a cognitively demanding area can transfer to other domains, the results of this study could be used as support. This is because the broad transfer hypothesis assumes that different cognitive demands in sport (e.g. handball) can result in certain cognitive skill profiles, which can also be measured in sport-unspecific tasks. Therefore, handball players' cognitive skill profiles would differ from those of athletes of other sports in sport-unspecific cognitive tasks. As already mentioned in chapter 1.2, past research has confirmed that athletes of various sports display different EF levels (e.g. Jacobsen & Matthaeus, 2014; Krenn at al., 2018). Moreover, by following the broad transfer hypothesis, positions with different cognitive demands within a sport, such as playmaker and goalkeeper in handball, would further exhibit different cognitive skills. Thus, EF differences based on playing position, which were found in this study, could develop because of the varying position-specific cognitive demands in sport. In this case, one could argue that playmakers exhibit higher cognitive flexibility and inhibition levels by reason of their position-specific cognitive demands throughout handball practice. Furthermore, the superior cognitive flexibility levels of players with two positions could be the result of more diverse and varying cognitive demands within handball practice compared to those solely playing one position. To sum up, the broad transfer hypothesis can be used as a possible explanation for the position-specific EF differences in handball, which were detected in this investigation.

However, neither past research nor the findings of the current study are able to illuminate the background for the found EF differences based on playing position and do not provide clear answers in the debate around the narrow and broad transfer hypotheses. At this point, it is still very unclear whether these cognitive skills are developed because of the demands of the respective positions or if players who already exhibit distinct abilities are more likely to be put in a specific position. More specifically, does practice as a playmaker enhance cognitive flexibility levels to a greater extent than other positions or are players with a greater switching ability more likely to be instated as center backs? Do players with two playing positions develop superior cognitive flexibility levels due to more varying cognitive demands throughout practice or are players with higher cognitive flexibility levels simply more likely to be instated on two different positions because of their superior cognitive skills? Among others, such as Koch and Krenn (2021), Holfelder et al. (2020, S. 12) addressed this question and called it *“nature vs. nurture problem”*. So far, no suitable and evidence-based answer can be given. The question if genetic influences (nature) or particular sport experiences (nurture) lead to higher EF levels remains open. Krenn et al. (2018) suggest that probably both of the just mentioned effects play a role to some extent.

4.1. Discussion of methods

In this study, three different test batteries were used to assess EF levels and coaches were asked to rate their players’ game intelligence on a 9-point scale. Naturally, the variables within one EF test battery were strongly correlated. However, and this can be used as criticism of the applied tests, some of the test batteries did not show a lot of connections to each other. Variables of the 2-back task were related to several variables of the Design Fluency test and to some variables of the flanker task. However, just one single association between a variable of the flanker task and the Design Fluency was detected. One would assume that variables such as the Contrast Measure and the correctly drawn designs of condition 3 of the Design Fluency, which are supposed to measure cognitive shifting (Swanson, 2005), would reveal numerous connections to variables of the flanker task such as errors on the red arrow, which measures cognitive shifting as well (Krenn et al., 2018). On the other hand, it seems quite obvious that a task where participants are asked to draw different designs under certain circumstances and a task where participants sit in front of a laptop and have to press a particular key as fast as possible show major differences. And yet, even though a lot of studies have used the Design Fluency and detected very interesting results (e.g. Huijgen et al., 2015; Lundgren et al., 2016; Vestberg et al., 2012), the reliability of the Design Fluency test and its applicability in team sports was doubted recently by Finkenzeller et al. (2021).

In addition to the easy and complex flanker task of Krenn et al. (2018), a new complex condition was implemented in this investigation. When a blue arrow was distributed, participants were asked not to react. The blue arrow correlated with an inhibition variable of the easy flanker as well as two shifting variables regarding the red arrow. Nevertheless, the complex flanker with the blue arrow did not seem to display more difficulties with respect to cognitive flexibility variables (red arrow). Analysis revealed significantly lower error rates on the red arrow in the blue task compared to the common complex flanker task. This result suggests that it was easier for participants to stick to the task when the red arrow was distributed in the second complex flanker task, possibly due to learning effects. To sum up, the newly implemented complex flanker task did not seem to add an important novel facet to the measurement.

The assessment of game intelligence in this study was based on Vestberg et al. (2020). Nevertheless, instead of solely questioning coaches, independent handball experts could have additionally been asked to rate players' game intelligence (Lundgren et al., 2016) in order to receive more valid and well-considered ratings. Yet, Scharfen and Memmert (2019) have previously addressed that assessing game intelligence is generally a quite challenging task.

5. Limitations and future implications

First of all, in addition to a small sample size (n = 82), the playing positions within this sample were not very well distributed. This led, for example, to a modest number of goalkeepers and pivot players. Moreover, the distribution of male and female athletes and their age as well as their league level was not very balanced. The majority of male athletes competed on an international level, which was not true for female athletes. As league level plays a crucial role in EF levels (e.g. Huijgen et al., 2015; Verburgh et al., 2014), this skewed distribution might have led to misinterpretations. Second, due to three different EF test batteries and various distinctions between the playing positions, a great number of tests were conducted in this analysis. However, lots of different tests result in an increased probability of committing a Type I error (Field, 2005). With respect to the applied test batteries, some criticism about methodological facets has already been given in the previous chapter. Nonetheless, the working memory task of this investigation partly contained extremely high error rates. Apart from the possible explanation that these participants with a high number of mistakes exhibit very low working memory levels, these high error rates could indicate that not all participants understood the instructions thoroughly. An extended familiarization within the test battery would perhaps help to increase the understanding of the instructions and would provide more valid data. In order to gain more insight to EF levels of handball players according to playing position, future research is needed. The results of this study suggested higher levels in playmakers and in back players (center, left and right back together) compared to other positions. However, the cognitive flexibility of solely left and right back players did not show a clear picture at all. Further research could assess the EF levels of very specialized playmakers and left and right back players in order to be able to differentiate the cognitive profiles of both playing positions. Additionally, investigating a much higher number of players with two positions (e.g. players in playmaker and wing positions, players in pivot and back positions) as in this study would make it possible to make distinct statements about the different EF levels between combinations of playing positions. Future studies could also take performance variables of team handball such as goals, assists, penalty goals, blocks, saves, and successful defense actions into account and have a look at the correlations between EF variables and performance along each playing position. Unfortunately, performance variables were not included in this investigation, due to economical reasons and a lack of a performance statistics program in Austrian handball. Finally, in order to give a possible explanation about the background of the development of EFs and whether specific EF levels are enhanced by playing a certain position or if players exhibiting certain EF levels are more likely to be instated on a specific position, studies in youth handball players should be carried out over a long period of time. Such longitudinal studies would further provide valuable insights for the debate about the narrow and broad transfer hypotheses.

6. Conclusion

The current investigation indicates some differences in EF levels according to playing position in team handball. Playmakers exhibited higher levels of inhibition and cognitive flexibility, which was also true for players who stated to play center back as second position (Lundgren et al., 2016). In addition, playmakers received the highest coach-rated game intelligence, albeit this difference not being significant. The results concerning EF profiles of wings, pivots, left and right back players were inconclusive, whereas back players (center, left, and right back) seemed to display higher cognitive flexibility levels and goalkeepers generally showed lower cognitive flexibility than other players. Moreover, results suggested higher levels of cognitive flexibility in athletes playing two positions compared to very specialized players (Montuori et al., 2019). Following the broad transfer hypothesis, these findings plead against an early specialization in youth athletes and for a broad athletic development (Koch & Krenn, 2021; Weber & Wegner, 2016) as well as for letting youth players play lots of different positions in handball. However, it is not possible to explain the background for the detected EF differences based on playing position. At this point, the role of genetic influences (nature) and development through particular sport involvement (nurture) remains unclear. To sum up, the current study contributes to some extent to a better understanding of EF levels according to playing position in team handball. However, further research is needed in this area in order to confirm the results of this investigation. Future studies addressing differences in general cognitive functions and EFs based on playing position would support the process of talent identification and improve individual athletic development.

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8. Appendix

List of tables

List of figures

Results of tests on normal distribution of test variables

variable	test	Kolmogorov-Smirnov	graphical evaluation - normal distribution yes/no	statistical outliers - excluded values	normal distribution yes/no
Correct Condition 3	Design Fluency	.005	yes		yes
Total Correct Designs		.079	yes		yes
Contrast Measure [3-(2+1)]		.061	yes		yes
Accuracy		< .001	yes	"1"	yes
inhib	easy flanker	.075	yes	"31"	yes
kon_reakzeit		< .001	no		no
inkon_reakzeit		.001	no		no
inkon_fehler		< .001	yes	"13", "16", "17"	yes
komp_farbinkon_reakzeit	complex flanker	.200	yes		yes
komp_farbinkon_fehler		< .001	yes	"8", "9"	yes
diff_meanRTrot_kongreinfach		.200	yes		yes
komp_farbinkon_reakzeit_blau		.166	yes		yes
komp_farbinkon_fehler_blau		< .001	yes	"4"	yes
diff_meanRTrot_blau_kongreinfach		.043	yes		yes
komp_blau_fehler		< .001	no		no
richtige_nback	2-back task	.043	yes	"5"	yes
falsche_nback		< .001	no		no
diff_richtig_falsch_nback		.009	yes	"-13", "- 17", " - 19"	yes
coach-rated game intelligence		.001	yes		yes

Results of tests on normal distribution of sociodemographic and sport-specific variables

variable	Kolmogorov-Smirnov	graphical evaluation - normal distribution yes/no	statistical outliers	normal distribution yes/no
age	< .001	no		no
years playing handball	.003	no	"16", "19"	no

Distribution of sociodemographic and sport-specific variables

sex	frequency
male	48
female	34
total	82

educational level	frequency
mandatory school	55
high school	13
currently at university	11
bachelor's degree	3
total	82

highest league level	frequency
regional level	2
national level	24
international level	56
total	82

current league level	frequency
regional level	2
national level	30
international level	50
total	82

1. position	frequency
wing	19
pivot	12
left/right back	25
center back	15
goalkeeper	11
total	82

2. position	frequency
wing	4
pivot	2
left/right back	12
center back	11
total	29

combination of positions	frequency
back and back	15
back and wing	12
back and pivot	2
total	29

center back as first or second position	frequency
playmaker	26
non-playmaker	56
total	82