DESIGN AND EVALUATION OF A REPRESENTATIVE, SENSORIMOTOR TEST TO ASSESS COMPLEX ANTICIPATION AND DECISION-MAKING BEHAVIOR IN SPORTS

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Abstract

Across high-performance sports, athletic attributes such as the physical, physiological, or anthropometrical ones are found to be performance-discriminating and -determining factors in sports. However, the determination of an expert athlete should consider a multidimensional view on an athlete's performance capabilities, taking perceptual-cognitive skills into account, also being essential for high-level performances. Still, there is an ongoing debate in science of how to set up performance environments best that combines perceptual-cognitive and motor skills of athletes to ultimately identify expertise in sports. The purpose of this thesis was to create and evaluate a multidimensional diagnostic tool that is able to capture perceptual-cognitive behavior and expertise with a representative task design and the involvement of complex, sport-specific motor responses. A domain-specific performer environment was created, with an *ecological dynamics* and *cognitive approach*, and the *expert performance approach* (Ericsson & Smith, 1991) as guiding frameworks from the literature. The designed representative, sensorimotor test consisted of varying attack actions presented on a life-size projection screen, and multiple, pre-specified defensive actions on a pressure contact plate system. First, the test was checked for reproducibility in test retest sessions, by analyzing the agreement of the given motor defense responses of team-handball players within a temporal-occlusion test paradigm. Results indicated reliable test metrics, as moderate agreement of the motor responses with the majority of the attack situations were revealed. Furthermore, players also gave faster responses with more visual information in the attack sequences, giving support for the practicability of the complex temporal-occlusion paradigm. Second, comparisons of response frequencies between elite and amateur team-handball players should reveal differences in complex decision-making behavior. Contrasting the performances of both groups, elite players demonstrated significantly more often a rather offensive-orientated response behavior, whereas amateurs showed significant preferences for rather defensive-orientated response behavior. The absence of decision time differences suggests that decision quality might be of stronger relevance than presumed in heuristic decision-making processes. Third, with regard to *embodied choices* (Lepora & Pezzulo, 2015), further between-group

comparisons were drawn with an in situ paradigm in a *simple heuristic* (Raab, 2012) context. Elite players were found to invest additional time for achieving higher accuracies in decisions significantly, pointing to speed-accuracy trade-offs in expert heuristic decision making. The findings in this thesis demonstrated the methodological complexity of analyzing perceptual-cognitive performances with respect to current scientific theories and models, when assessing expert anticipation and decision making. The overall results contribute to recent developments in psychology and cognition science in sports, while having several implications for theory and practice.

Kurzzusammenfassung

Im Hochleistungs- und Spitzensport-Bereich sind die individuellen Eigenschaften eines Athleten, wie zum Beispiel physische, physiologische oder anthropometrische Attribute, als leistungs-diskriminierende Faktoren für den Erfolg im Sport determiniert worden. Für die Identifikation von sportlicher Überlegenheit sollte jedoch ein multidimensionaler Blick auf die Leistungsfähigkeit von Athleten geworfen werden, welcher ebenfalls die für den sportlichen Erfolg notwendigen perzeptuell-kognitiven Fähigkeiten mit berücksichtigt. In der Wissenschaft gibt es daher aktuelle Debatten über methodologische Strategien, wie bestmöglich Leistungsumgebungen geschaffen werden sollten, die in kombinierender Art und Weise perzeptuell-kognitive und motorische Fähigkeiten abbilden und schlussendlich sport-spezifisches Verhalten und einhergehender Expertise identifizieren können. Zielstellung der vorliegenden Arbeit war es, ein multidimensionales Diagnoseinstrument zu entwickeln und zu evaluieren, welches perzeptuell-kognitive Expertise mithilfe von repräsentativen Aufgabenstellungen und komplexen, sport-spezifischen Bewegungsantworten messbar machen kann. Dazu wurde eine handball-spezifische Leistungsumgebung geschaffen, die in ihrer Konzeption auf *ecological dynamics-* und *kognitive Ansätze*, sowie den *expert performance approach* (Ericsson & Smith, 1991) zurückgriff. Der entwickelte repräsentative, sensomotorische Leistungstest beinhaltete Leinwand-basierte, handball-spezifsche Angriffssequenzen, sowie multiple Abwehrantworten auf einem mit Kontaktsensoren verbundenen Sportboden. Anfangs wurde der Leistungstest auf Reproduzierbarkeit überprüft. Dazu wurde in einer Test-Retest-Studie die Übereinstimmung aller gegebenen Abwehrantworten von Handballspielern innerhalb eines zeitlichen Okklusions-Paradigma analysiert. Moderate Übereinstimmungsmaße für die Mehrheit der Abwehrantworten induzierte reliable Testmetriken, die Spieler erzielten dabei ebenfalls schnellere Antwortzeiten mit steigender visueller Information, untermauernd für Anwendbarkeit des komplexen Okklusions-Paradigmas. Weiterhin sollten durch Vergeiche der Antworthäufigkeiten von Leistungs- und Amateur-Handballspielern Unterschiede in komplexem Entscheidungsverhalten zu Tage gebracht werden. Spitzen-Handballer zeigten dabei signifikant häufigeres offensiv-orientiertes Entscheidungsverhalten, wohingegen Amateur-Handballer signifikant häufiger defensiv-orientiertes Entscheidungsverhalten tendierten. Absente Gruppen-Unterschiede in Entscheidungszeit suggerieren eine stärkere Bedeutung der Entscheidungsqualität in heuristischem Entscheidungsverhalten. Abschließend wurden Gruppen-Vergleiche mit einem in situ-Paradigma in einem *embodied choice*- (Lepora & Pezzulo, 2015) und *simple Heuristiken*-Kontext (Raab, 2012) gezogen. Sigifikante speed-accurracy trade-offs im Entscheidungsverhalten wurden dabei offengelegt, in denen Spitzen-Handballer scheinbar zusätzliche Zeit zugunsten von höherer Entscheidungsgenauigkeit investieren. Die vorgelegte Arbeit verdeutlicht aktuelle, methodologische Anknüpfungspunkte zur Messbarmachung von Antizipations- und Entscheidungsfindungs-Expertise.

Chapter 1

Capturing Anticipation and Decision-Making Behavior and The Relevance of Motor Components

In sports, athletes are constantly challenged to give their best in order to be successful in their particular sports domain. Calling up and improving sportive performance is a central building block not only for athletes and coaches, but also for scientists. In order to better understand how performance comes about and how performance can be defined, also depending on the perspective from which performance is viewed on, sports performance analyses attempt to objectively describe sports behavior action variables in practice, competition, and science (McGarry et al., 2013).

The general aims of sports performance analysis are the advancement of the scientific understanding of performance, as well as providing the coaching process with augmented information in sports practice (McGarry et al., 2013). From a practical point of view, performance analyses can help to set reference points within the context of long-term athletic development (Lloyd & Oliver, 2012), and specifically to setting benchmarks that can discriminate expert and nonexpert athletes (Allen et al., 2014; Drikos & Tsoukos, 2018; McIntosh et al., 2019). From a scientific point of view, the application of performance analyses can result in sport-specific performance models in each sports domain and discipline (e.g. individual or group requirements for achieving elite performances in team-handball). Additionally, models can be created that are also able to describe running processes when athletes are actually performing (e.g. *Situation Model of Anticipated Response Consequences in Tactical Decisions – Extended and Revised*; Raab, 2014).

Scientific performance analyses are mostly emphasized on studying individual athletic attributes such as physical, anthropometrical, technical, physiological and tactical attributes, conducted in several sports disciplines so far (Ávila-Moreno et al., 2018; Gharbi et al., 2015; Liu et al., 2016; Mahoney et al., 1987; Passos et al., 2016; Wagner et al., 2014). As an example from research in field hockey (Elferink-Gemser et al., 2004), elite and sub-elite youth players were compared regarding their anthropometric, physiological, technical, tactical and psychological features. Statistical analyses with the performance data demonstrated that the elite youth players outperformed the sub-elite youth players in dribble performance in a peak and repeated shuttle run (technical), in general tactics and tactics for possession and non-possession of the ball (tactical), and also in motivation (psychological).

Despite the consideration and the discriminating value of these individual features and their anchoring in sports science and practice, the related predictive validity regarding performance and talent identification is limited, especially when these features are considered individually (Bennett et al., 2018; Bergkamp et al., 2019; Wagner et al., 2016, 2019, 2020). It appears only logic that when an athlete is in good physical shape, he or she can reach highest performances. In individual sports, sprinters in track and field rely strongly on power and coordination in order to accelerate as fast as possible for reaching the highest possible velocity (Schenau et al., 1994). This automatically narrows the range of performance analyses methods with the respect to the nature of the discipline itself. Successful performances of team sport athletes, such as team-handball, requires a more complex interplay of individual performance of each player, tactical components and the interaction with the team itself (Wagner et al., 2014). It can be that players are identified to be inferior in the physical components, but it is not clear, if the player compensates these deficits with a superior sense for tactical behavior, hardly to capture with classic performance analyses tools. On this account, current voices in sports science criticize that isolated examinations of individual factors do not seem to be fully representative anymore to reflect the actual on-field performance of athletes with its underlying contextual constraints (Bergkamp et al., 2019, Lidor et al., 2005; van Maarseveen, Oudejans et al., 2018, van Maarseveen, Savelsbergh et al., 2018). It seems worthwhile to shift the focus more on holistic or multidisciplinary approaches in performance analyses and talent identification, which enables a combined consideration of an athletes' physical as well as psychological (perceptual-cognitive) features. Quite especially, there is a growing awareness in practice and science for the meaningfulness of perceptual-cognitive skills of athletes, since perceptual-cognitive skills are also determined to play a fundamental role in talent identification in sports (Bangsbo, 2015; Bennett et al., 2018; Bergkamp et al., 2019; Sherwood et al., 2019; Woods et al., 2016).

To date, first attempts are made to apply such multidisciplinary performance analyses that include the perceptual-cognitive components into the bigger picture of sport-specific performance. However, it still remains a challenging endeavor to explicitly create representative performance tests that deliver valid statements about actual on-field performance capabilities of athletes, especially in a complex and dynamic environment such as team sports. Still, more research is needed to extend the scientific knowledge about holistic performance capabilities, and in this course how expert performance can be identify best and trained as well. This thesis makes an attempt to create a multidisciplinary performance test that can assess sport-specific, perceptual-cognitive skills in a representative performer environment.

The Meaningfulness of Perceptual-Cognitive Skills in Sports

Preliminary to the following consideration of perceptual-cognitive skills in sports, in the English-speaking literature, the terms *skill* and *ability* are used interchangeably in the context of the perceptual-cognitive system in sports. In the book *Anticipation and Decision Making in Sport* (Williams & Jackson, 2019b), a collection of works from leading scientists in this field and edited by A. Mark Williams and Robin C. Jackson, there is no clear boundary in the differentiation between *skill*(*s*), which described as learned behavior, and *ability*, described as natural or innate. Therefore, this thesis also makes use of the term *skill* or *skills* when describing perceptual-cognitive aspects (or anticipation and decision-making aspects), however, in some cases, the term *ability* could also be applied in the same way.

In general, perceptual-cognitive skills are defined as an ability that allows for the identification and acquisition of environmental information to integrating it in existing knowledge, in order to facilitate a selection of appropriate responses that should be executed subsequently (Marteniuk, 1976). Based on the meta-analysis of Mann et al. (2007) on perceptual-cognitive expertise in sports, the generic term *perceptual-cognitive skills* includes a wide range of types such as cue usage, gaze behavior, information processing, visual attention, visual search, and also anticipation and decision making. Researchers have shown that perceptual-cognitive skills are essential components of performance in a variety of domains, including law enforcement (Phillips & Burrell, 2009; Suss & Raushel, 2019), medicine (Gigerenzer & Galesic, 2012; Marewski & Nadin, 2017), or finance (Bondt et al., 2013), just to name a few.

In team sports, which is characterized as a complex and rapidly changing (and therefore uncertain) performance context (Raab, 2012; Raab & Gigerenzer, 2015), athletes are challenged to constantly process information while acting under time and information constraints. Tom Brady for example, stated as the most successful quarterback in the history of American Football, is challenged at any time of the game to make accurate decisions under time and game pressure while anticipating what tactical consequences his decisions are going to have. Taking a closer look at his career stats outlines his incredible ability to transforming thoughts into actions. Today, Brady is still breaking records, despite being in his mid-40s. Just to have a glimpse on his individual achievements in 22 National Football League (NFL) seasons, Tom Brady leads the all-time NFL stats in passing yards (84.520; 2nd rank: 80.358) touchdown passes (624; 2nd rank: 571), quarterback wins (243; 2nd rank: 186), and seven Super Bowls above all (Stats perform, 2022). The question that remains is, why is Tom Brady able to be that successful? It only appears logic that his expertise in making the right decisions and foreseeing upcoming situations on the field is the essence for his outstanding success, since quarterbacks are the determined to be the most important decision makers in an NFL team. This example illustrates that perceptual-cognitive skills in sports, such as anticipation and decision making, are crucial elements in many sports disciplines for successful individual and team performances (Bonnet et al., 2020; Loffing & Hagemann, 2014; Tenenbaum et al., 1993; Wagner et al., 2014).

Anticipation and decision making in sports can hardly be separated from one another. Araújo et al. (2017) state that decision making is often related to aspects of perception, attention, memory, learning, and finally anticipation as well. Furthermore, in the *Handbook of*

Sport Psychology by Tenenbaum and Eklund (2012) there is no terminological differentiation between anticipation and decision making.

Meanwhile, there is robust evidence in sports science research determining anticipation and decision-making components as performance-discriminating features, necessary for expert performance in sports (Ashford et al., 2021; Mann et al., 2007; Silva et al., 2020; Travassos et al., 2013). For this reason, it seems inevitable for athletes to develop discipline-specific anticipation and decision-making skills which enables them to meet the dynamic challenges of the play (Williams & Jackson, 2019a). In the last decades, there has been a growing interest in sports science in the processes and mechanisms underpinning perceptual-cognitive skills such as anticipation and decision making as integral parts of it (Williams & Jackson, 2019b).

Anticipation in Sports

In cognitive neuroscience, one can find the term of the *predictive brain*, a concept that outlines the process of "looking into the future" by components such as prediction, preparation, prospection, expectations or anticipation in a variety of cognitive domains (Bubic et al., 2010; p. 1). According to Butz et al. (2004), anticipation is the impact of predictions on current behavior, for example, choices or actions resulting from these predictions, while predictions are defined as the representation of an event. Riegler (2001) illustrates in his paper how impossible it is for the cognitive system to find the best option in problem-solving tasks. Facing a problem, surely there is a repertoire of options of how to solve it, even after narrowing it down to the most realistic ones, but the spatial-temporal course for this process does not allow an individual checkup of all possible solutions. Therefore, the cognitive system falls back to similar or already existing knowledge about the problem, combining the most suitable choice with a tolerable amount of risk of error for a prediction, or with an anticipation of a decision outcome.

As sports, and team sports in particular, is by nature characterized by its constant spatial-temporal constraints, complicated by the little amount of time available during play, the cognitive necessity to anticipate a decision or an action, in order to *solve a problem* (in terms of situational accurate actions and decisions), is an essential criteria for athletes to be successful (Williams & Jackson, 2019b). As examples from real life situations in sports, anticipation is required in volleyball attacks when preparing a smash, in defensive moves in karate, or in penalty throws in team-handball when foreseeing the goalkeeper's movements.

The interest of scientists in anticipation has been growing over the last 50 years. In 1978, Jones and Miles laid the foundation stone for ongoing examinations in anticipation in sports with their study using a film-based, temporal-occlusion paradigm in tennis (Jones & Miles, 1978). The temporal-occlusion method was ahead of its time, since the technological possibilities at that very time were limited. In this experiment, they presented participants (skilled and lesser skilled tennis players) with short video sequences of tennis serves on a video screen. The video sequences were edited, in the form of occluded, either 42 ms before, at, or 335 ms after the tennis player's racket in the video made contact with the ball. Based on the visual information given, the participants had to make a judgement where the ball would land with making a cross in one of three response boxes on a scaled, schematic representation of a tennis court. What the authors found was that the expert tennis players were significantly more accurate in their judgements of the ball landing spot, especially in the early occluded video sequences, where they only could rely on kinematic/postural cues of the opponent. This approach paved the way for upcoming investigations, foremost by Bruce Abernethy, later stated as the "founding father of modern-day research on this phenomenon" (Williams & Jackson, 2019a; p. 4), with several follow-up studies using this paradigm (Abernethy, 1988; Abernethy & Russell, 1984, 1987). Abernethy modified this method by the creation of the spatial-occlusion paradigm, in which different sources of information, more specifically kinematic cues such as single body parts, were excluded in the presented occlusion conditions (Abernethy & Russell, 1987). That allowed the researcher to identify decisive kinematic/postural cues in an upcoming event as an indicator for changing judgement accuracy in comparison to non-occluded video conditions. After the turn of the millennium, the temporal- and spatial-occlusion paradigm was extended by the point light display, where the opponents' movement is visually reduced to its underlying relative motion with the usage of light dots on joints or other selected body parts of an opponent, depending on the area of interest (Huys et al., 2009). To date, current examinations in the field of anticipation in sports still make use of these paradigms, especially the temporal-occlusion technique, paired with modern laboratory technologies such as virtual reality environments (Bideau et al., 2009; Vignais et al., 2015), eye-tracking analyses (Kredel et al., 2017), pressure-sensitive contact plate systems (Vaeyens, Lenoir, Williams, & Philippaerts, 2007; Vaeyens, Lenoir, Williams, Mazyn et al., 2007), and even fMRI scans with video projections (Bishop et al., 2013).

Theories and Models of Anticipation in Sports

What 50 years of research on anticipation in sports (and related perceptual-cognitive skills) has revealed is summed up in the review of Gredin et al. from the year 2020. Their review illustrates that the mechanisms behind anticipation are two-fold.

Kinematic information. First, kinematic information is one general source that is used during anticipation in sport. Kinematic information is perceived by certain visual search strategies, enabling the athlete to detect and use kinematic cues from an opponent's motion in an unfolding action, or even from sportive equipment such as ball flight curves (Gredin et al., 2020). Detailed insights about the proportions of kinematic information was revealed by scientists who especially conducted gaze behavior analyses in anticipation experiments. Using mobile eye-tracking devices, Savelsbergh et al. (2002) compared novice and expert goal-keepers in a penalty setting in terms of predicting the ball flight direction. Beside higher prediction accuracies of experts in ball flight directions, it was also found that experts spent more time fixating task-relevant cues of the penalty taker, such as the placement of the non-kicking foot. A further method identifying the importance of kinematic information were retrospective verbal reports about the information processing during the action (Eccles, 2012).

One model of how to integrate kinematic information during anticipation was created by Müller and Abernethy (2012) in striking sports. Their model illustrates that the priority of processing during anticipating and intercepting varies depending on the task-relevance of the informational variables given. In simple words, when unfolding kinematic cues of the opponent's movement can become a reliable predictor to a forthcoming action, athletes constantly update their anticipatory judgements in correspondence to the weighting of the kinematic cues in the sequences of the unfolding movement. What this model does not consider is the impact of non-kinematic information on anticipation performance, which gained more attention by scientists in recent years.

Context information. The second mechanism behind anticipation is the utilization of non-kinematic information, more specifically context information, which were found to have a significant influence on anticipation when kinematic cues are absent (Cañal-Bruland & Mann, 2015).

Several experts in this research field used the term *context information* for the designation of non-kinematic information (Cañal-Bruland & Mann, 2015; Loffing & Cañal-Bruland, 2017), what caused some confusion in the scientific community, as non-kinematic information was used interchangeably with the term *situational probabilities* (Abernethy et al., 2001), what also describes event probabilities during anticipation. The review of Gredin et al. (2020) as well as the work of Williams and Jackson (2019a) brought some clarification in the exact usage of this term, since situational probabilities can also be considered as a specific source of context information (Williams & Jackson, 2019a).

Context information is a generic expression for a broad range of domain-specific knowledge that subsequently change the situational probabilities. These sources of information occur always prior to perceived kinematic information provided by the opponent. During an unfolding action, an athlete can possess either *dynamic*, domain-specific knowledge of the current match status (Farrow & Reid, 2012), and opponent positioning (Loffing & Hagemann, 2014), or also *stable* knowledge about the patterns of play (Loffing et al., 2015), or opponents action tendencies (Helm et al., 2020; Lüders et al., 2020) for example.

A current model in anticipation research is stating that anticipatory judgements are made when separate processes are integrated and building on one another in a sequential way (Raab, Bar-Eli et al., 2019). The perceived environmental information is encoded in preparation for the further usage in the internal mechanisms, in order to converting it into a meaningful representation (Williams & Abernethy, 2012). Subsequently, this enables the athlete to interpret the environment with a resulting initialization of an action. There are several cognitive models investigating the dimensions of anticipation in sport. The computational model of Busemeyer and Johnson (2004) assumes that the sequential information processing runs until a certain threshold of preference for one decision or action is met (Johnson, 2006). Another computational model, the theory of Long-Term-Working-Memory by Ericsson and Kintsch (1995) suggests that experts in sports have the ability to decide faster and better than nonexperts due to their acquired retrieval structures from practice and training, facilitating a quick encoding of information, while avoiding the limitations of short-term and long-term memory (Ericsson & Lehmann, 1996). State-of-the-art models, such as the Bayesian framework (Gredin et al., 2020; Helm et al., 2020; Vilares & Kording, 2011) increase in complexity, as this particular model offsets up- or down-weighted reliability of context information while simultaneously integrating kinematic information into complex statistical models.

Anticipation is an important field of research in sports, because it determines sport-specific behavior and expertise of athletes. The degree of anticipatory skills and its impact on athlete performance is meanwhile well researched in many of the sports domains, in particular racket sports and team ball games (Williams et al., 2018)

The mechanisms of anticipation often coincide with further other linked perceptual-cognitive skills, and quite particularly with the phenomenon of decision making. Williams and Jackson, two of the leading scientists in perceptual-cognitive research in sports, dedicated their book *Anticipation and Decision Making in Sport* (Williams & Jackson, 2019b) to the last four decades of research to these two specific skills. The following section will introduce the topic of decision making and its underlying mechanisms in sports, an historical overview and decision-making theories and models.

Decision Making in Sports

Decision making is a complex human behavior that has been researched intensively during the last decades across a large range of disciplines, ranging from cognitive psychology to economics. Even though decision making is regarded as a rather behavioral phenomena in science, there are current developments in cognition science and neuroscience trying to assess the internal processes of decision making in the brain. With the respect to the span width of decision making and the purpose of this thesis, a short glimpse about the cognitive and neuroscientific proportions of decision making will be given in the following.

Fundamentally, a broad definition of decision making is given by Hastie (2001) who describes decision making as the ability of an individual to select functional actions to achieve a specific task goal from a number of action possibilities. In her review and conceptual framework, Fellows classifies decision making as one part of the executive processes in humans synthesizing different types of information, such as multimodal sensory inputs, autonomic and emotional responses, past associations, and future goals (Fellows, 2004). These types of information must be integrated with further influencing factors such as timing, uncertainty, cost-benefit, and risk, in final preparation for the selection of an appropriate action (Fellows, 2004). Making appropriate decisions, as a function of action, is constrained by the needs for rapid execution and flexibility, in order to adapt changing environments. According to Wang and Ruhe (2003), decision making itself is determined by certain strategies that are applied when a set of decisions are at hand. The selection of the final decision depends on the audit of certain selection criteria. Wang and Ruhe, scientists from cognition science, identified four prominent decision-making strategies: *intuitive, empirical, heuristic, rational* (2003).

With regard to sports, decision making is considered as information usage being provided by a players' recent situation, combined with the players' ability to use prior knowledge about a sports situation, in order to plan, select, and execute (an) appropriate goal-directed (set of) action(s) (Causer & Ford, 2014).

Modern-day research on (judgement and) decision making began more or less with Simon's alternate concept of *bounded rationality* in the year 1955 (Simon, 1955). In contrast to the economical rationality which assumes an ideal model in decision making, his concept hypothesizes that the environment a person acts in bounds the decisions to a rather sufficient or acceptable quality level, allowing for fast and frugal choices. In the 1970's, Amos Tversky and Daniel Kahneman introduced the later labeled *heuristics and biases* paradigm, in order to study human behavior from a cognitive view (Kahneman & Tversky, 1979). This paradigm assumes that decisions are fast and simple, as a product of intuitive thinking (heuristics) when a certain degree of risk or uncertainty is present. The awareness for scientific applications of these concept and paradigms in sports psychology began surprisingly late at middle of the first decade of the 2000s. Already in 1985, Gilovich, Vallone and Tversky have published a groundbreaking work that found much attraction in a broad variety of research areas, but it was less regarded in sports psychology till the year 2006. Their study on the *hot hand* (and its absence) in basketball maintained that the probability for hitting the basket again is equal for a player who hit two or three times in a row and for a player who missed two or three times in row, not being regarded as *hot* (Gilovich et al., 1985). With the establishment of the Journal of *Psychology of Sport and Exercise* in the year 2000, a stronger awareness for decision-making research was developed, and in 2006, Michael Bar-Eli and Markus Raab started to put an emphasis on sports psychological research by applying theoretical (judgement and) decision-making perspectives to sports (Bar-Eli & Raab, 2006). With ongoing time, new models and theories were developed shifting to rather dynamic and probabilistic, and therefore more realistic approaches. Currently, state-of-the-art research is not only interested in the understanding of cognition and action in sports and how players and athletes make their decisions, but also how these decisions are expressed by movements. The following section will briefly describe selected decision-making theories and models that are related to the topic of this thesis.

Theories and Models of Decision Making in Sports

In a broader sense, decision making in sport psychology is supported by the four pillars, namely the *economic approach*, the *cognitive approach*, the *social* approach and *ecological* *dynamics* (Raab, Bar-Eli et al., 2019). Three of these approaches are explained in more detail in the section below, the *social approach* is closer related to the field of social cognition, which focusses on cognitive processes as basis for social interaction, what is not a part of this thesis (for details of the *social* approach, please see Raab, Bar-Eli et al., 2019).

Economic Approach. The *economic approach* in decision making in sports is inspired by behavioral aspects of humans in economics. Daniel Kahneman, behavioral economist and Nobel Prize winner, stated that “sports research is a great idea, because people here take many decisions that are of great importance to them under standard conditions” (D. Kahneman, personal communication with Michael Bar-Eli, 2008). Especially the debate over the *hot hand*, and the penalty kick phenomenon in soccer was often associated with economic explanatory approaches towards human behavior. In his doctoral dissertation, Csapo (2015) investigated the *hot-hand* phenomenon in basketball underlying defensive pressure. No evidence for a *hot-hand* effect was found when players followed a *hot-hand* belief towards a *hot* player with increasing their defensive pressure on the player (closer defending or double teaming). Even a *hot-hand* behavior on defense was not considered as an adaptive behavior. This example from sports inspired ongoing examinations dealing with successful or unsuccessful *streaks* of investments in the stock market for example (Kahneman & Egan, 2011).

With regard to the penalty kick phenomenon, the economist Ignacio Palacios-Huerta illustrated in his book *Beautiful Game Theory* ‘how soccer can help economics’ (Palacios-Huerta, 2014). As an example, Bar-Eli et al. (2007) revealed that the optimal strategy for soccer goalkeepers would be to stay in the center rather than jumping either left or right. The norm for a goalkeeper during play is to act, whereas inaction (staying in the center) is associated with worse feelings, therefore leading to a bias for action. Nevertheless, Bar-Eli et al. (2009) define such a biased behavior only when assuming that the goalkeeper’s utility function displays maximizing strategies of the chances to stop the ball, being in line with traditional economic theories (Edwards, 1954).

Cognitive Approach. The *cognitive approach* describes that when making a choice (e.g. either passing or shooting a ball), several processes, for example cue-use in perception/recognition or recall in memory, run separately, what subsequently affects the final choice (Raab, Bar-Eli et al., 2019).

In relation to the *hot-hand* phenomenon by Gilovich, Vallone and Tversky (1985), the concept of *simple/fast and frugal heuristics* by Gigerenzer (2000) laid a cornerstone for subsequent investigations in heuristic decision making in sports (Raab, 2012). In simple words, a heuristic is a simple rule of thumb, also described as "a strategy that ignores part of the information, with the goal of making decisions more quickly, frugally, and/or accurately than more complex methods" (Gigerenzer & Gaissmaier, 2011, p. 454). Within this theory, further sub strategies of heuristic decision making in sports were developed, such as the *take-the-first* (choosing the first option that comes to mind) by Johnson and Raab (2003), or *take-the-best* (searching for cues in the order of cue validity) heuristic by Gigerenzer and Goldstein (1996), with the aim to specifying players' decision-making behavior. Specifically, the *take-the-best* heuristic utilizes game-related cues in a sequential manner (distances to the goal, team mates, or opponents) that are sorted in terms of their validity, with a following decision based on the first cue that discriminates between options. Investigations on heuristic decision making are often experimentally-orientated, where selected paradigms (e.g. in situ paradigm; temporal-occlusion paradigm) can be applied to investigating decision-making and option-generation processes (Belling et al., 2015), or to modelling choices and reaction times (Johnson, 2006).

Ecological Dynamics. The *ecological dynamics* approach was established in the late 1970's, when concepts and methods from the ecological and dynamic perspective on perception and action were synthesized (Kugler et al., 1980; Turvey, 1977). Amodal theories on perception and action propagated theories of memory enrichment through mental representations of schemas or programs. These mental representations are considered as enhancing for the meaning of perceived stimuli in order to interpreting the environment and preparing a bodily action. Meanwhile, there are non-representational approaches, suggesting that perception and cognition are embedded and embodied, involving the motor system as an interacting component in a performer-environment system. Especially Keith Davids and colleagues opened up opportunities for the implementation of the idea that action is, in its principles, a cognitive process rather than a simple transformation of a mental process, into the field of sport science (Davids et al., 1994). One prominent concept within this approach is the ecological dynamics rationale by Araújo et al. (2006) which links the concept of representative designs by Brunswick (1956) to decision-making. Within this concept, assumptions are made that cognition (seen as information processing) is the continuously working maintenance in a solid performer–environment, and facilitated by closely coordinated action and perception (Araújo et al., 2006). As an example from practice, one can imagine what a baseball player has to accomplish when trying to catch a fly ball. In contrast to classic (amodal) theories assuming a decoupled processing of a) perceptions of the ball's flying dynamics, b) cognitive computation about ball bounce spot and required pace of running to reaching it, and c) initialization of running actions, the ecological dynamics perspective supposes a coupled, simultaneous interaction of these three factors. When an athlete or player interacts with his or her environment by performing sport-specific actions, then the set of options for actions (*affordances*) steadily shifts and transforms, by remaining environment conditions (Gibson, 2014). Therefore, decision making appears to be a rather *emergent* behavior (Araújo et al., 2006).

Today, the current theory of the *ecological dynamics* defines decision-making behavior as action-based and non-representational process, and cognition is the continuous, active maintenance of a robust performer– environment system, possible by perception and action being closely coordinated with one another (Araújo et al., 2017). It also outlines that expertise can be assessed best when individuals are required to interact with the varying constraints/characteristics of the performer-environment system.

Research on Anticipation and Decision Making in Sports Science

Over the last decades, much has been done to understanding the mechanisms behind anticipation and decision-making processes in sports. One central motive for this matter is that anticipation and decision-making skills appear to be fundamental for high-level performances and success in many of the sports domains. In order to reflect the competitive nature of sports and how anticipation and decision making contribute to elite performance, scientists therefore applied the framework of *expert performance approach* (Ericsson & Smith, 1991) from cognitive psychology.

Expert Performance Approach. Generally, the definition of expertise refers to the ability to consistently demonstrate superior levels of proficiency within a particular domain over a certain amount of time (Starkes, 1993). The delivery of high-performances is a fundamental aspect to reach superior levels of expertise in a wide variety of performance domains, such as music, economy and sports. Especially the field of sports is a suitable testbed to control and adjust the relation between performance and expertise. Over the last decades there has been a growing interest in analyzing sports performance (McGarry et al., 2013), which helps to create performance-determining profiles in each sport discipline, shaping the understanding of sports expertise. The knowledge gained from that contributes not only to talent identification and detection processes, but also to the evaluation of the changing requirements to achieve superior expert performance (Ericsson, 2006; Williams et al., 2008; Williams & Reilly, 2000). The *expert performance approach*, created by Ericsson and Smith (1991), was developed to provide a cognitive framework which aims for the targeted exploration of the cognitive components of human supreme performance. The approach describes that when assessing expert performance it is essential to develop a representative environment with equal task constraints, but under replicable and standardized conditions for all individuals tested (Ericsson & Williams, 2007). The approach is a three-stage model, offering possibilities for the empirical analysis of expertise. The first stage points to the observation of the naturalistic expert performance behavior for capturing essential expert variables within the selected domain, and it also points to the determination of representative tasks that involve the picked variables suitable for a valid reproduction in lab- or field-based experimental settings. The second stage refers to the usage of the created representative tasks for the subsequent identification of the underlying mechanisms, which mediate expert performance, and being measured by process-related procedures (e.g. eye-tracking recordings, verbal report protocols, representative task manipulations). Ultimately, when these mediating mechanisms which also decisive components for expert performance are once identified, scientists, after all, can evaluate and determine how experts acquire and develop these components, while considering the consistency of the components itself.

In sports science, the application of the *expert performance approach* (Ericsson & Smith, 1991) brought to light several indications for superior perceptual-cognitive skills in athletes. In the field of anticipation and decision making, Wickens et al. (2015) takes three factors as a basis why experts are superior than novices: i) better information pick up and processing strategies of the most valid cues from their situational environment (Smeeton et al., 2019), ii) greater domain-specific knowledge of situational probabilities and superiority knowledge of required action-goal concepts in relation to long-term working memory (Ericsson, 1998; Gredin et al., 2020), iii) more extensive coupling of perceived cues, situational probabilities, and the possibilities of decision outcomes (Gredin et al., 2020).

Anticipation Behavior and Expertise in Sports

A well-established research paradigm which still is strongly used today in anticipation experiments is the temporal-occlusion (TO) paradigm (Jones & Miles, 1978). As mentioned before, TO describes the method to occlude video sequences at different time points in order to identify key events or kinematic cues within the unfolding actions of players in video presentations. The experimental setups mostly consist of a video screen (in the form of a life-size projection or a computer screen), with the participants placed in front of the screen in a standing or sitting position. The presented videos showed typical game scenarios from a particular sports domain, being successively occluded before a key event to single video clips with varying viewing time and kinematic information. A typical example from anticipation research is the execution of a tennis stroke, where the key event in the full sequence was the racket-ball contact at time point t_0, and the sequence was occluded ahead of the key event at different time points, such as 80 ms before the contact (t_1), 160 ms before the contact (t_2), 240 ms before the contact (t_3), for example. The choice of the temporal intervals, where to occlude is up to the researchers with regard to the experimental test design. The application of the TO paradigm (Jones & Miles, 1978) allows for the evaluation of related response outcomes, such as gaze tracking, action prediction, and prediction accuracy over the time course of the unfolding action, either in a motor or nonmotor manner. The TO paradigm (Jones & Miles, 1978) was often applied on anticipation expertise, showing that experts anticipate the outcomes from kinematic movement patterns better, and especially at earlier time points in the video (Farrow et al., 2005, Smeeton et al., 2019, Tenenbaum et al., 2000; Williams et al., 2002).

Empirical Findings on Kinematic Information. In team sports such as team-handball, a high dynamic and complex team sport ball game, anticipation was often examined from a simple and isolated perspective on either team-handball goalkeepers expecting a penalty throw, or field players executing various types of throws (Cocić et al., 2020; Loffing & Hagemann, 2014; Loffing, Sölter et al., 2015). Depending on the research questions and its methodological approaches, the experiments revealed multiple facets of how anticipation outcomes are affected by picking up and processing information in specific situations in team-handball. Loffing and Hagemann (2014) investigated the anticipation abilities of team-handball goalkeepers by the analyses of prediction performance of the type of throw in penalty situations. Videos of team-handball penalties with varying amount of viewing time were presented, and participants were tested individually in a seating position in front of a notebook monitor. The task for the participants consisted of predicting a penalty-taker's type of throw (hard shot or lobbed shot) by pressing a respective button on a keyboard. By calculating the percentage of correct responses, it was found that the ability to identify kinematic cues affects the prediction of the type throws. Furthermore, significant improvements in correct predictions with increasing viewing time were also revealed.

Cocić et al. (2020) used occluded video sequences of team-handball throws of backcourt field players towards the goal. The video clips in this study were presented to team-handball goalkeepers and novices on a projection screen, who had to predict the direction of the throws after the end of each of the video clips via keystroke on the keyboard. Here, expert advantages were detected in the prediction accuracies of the throws and faster response times in favor for the goalkeepers.

Besides the above described team-handball goalkeeper study, another team sports example found superior anticipation abilities of experts. In volleyball, Loffing, Hagemann et al. (2015) aimed for a comparison of skilled volleyball players with novices regarding their anticipatory performance in the context of left- or right-handedness of an opponent. In a video-based test setup, players were shown video sequences with manipulated information content (increasing viewing time). The players then were asked to predict the type of volleyball attack (smash or lob) of a right- and a left-handed attacker via button press on a keyboard. Clear effects for expertise were detected, as skilled volleyball players demonstrated higher overall accuracy than novices in the prediction of the presented attacks. They also demonstrated better predictions of attacks when little amount of kinematic information in the video sequences was provided, especially pronounced in right-handed attacks. Beside the fact that volleyball players were identified to use kinematic information in earlier time points of an unfolding action due to their domain-specific anticipatory capacities, additional performance disadvantages were also found when players have to compete against left-handed opponents.

In rugby, a video-based study by Jackson et al. (2006) revealed significant differences between expert and recreational rugby players in the anticipation of an attacker's movement directions, either with or without deceptive actions in one-on-one situations. The participants in this study were asked to imagine to be the defender, and to give a physical response in the direction they assume the attacker in the life-size video sequence would go to. The novices demonstrated higher susceptibility to the deception moves in the videos, resulting in worse response correctness.

In soccer, Roca et al. (2011) used a representative task with video sequences showing life-size game scenarios of 11 vs. 11 situations in a soccer match, occluded 120 ms prior to the player in the video received the ball. Skilled and less skilled soccer players were required to anticipate the upcoming actions of their opponents, by giving a verbal response about their selected decision of how to respond in the particular moment. Based on their anticipatory capacities and their complex domain-specific memory representations, the skilled participants outperformed the less skilled counterparts in correct intention predictions and appropriate response actions.

In striking sports such as tennis, baseball, cricket, badminton, squash, or table tennis, skilled anticipation is necessary to constantly hit an object at fast pace with highest precision under time pressure. The review of Müller and Abernethy (2012) summarized the empirical evidence from research on expert anticipatory skill in striking sports. Similar to the advanced cue usage during anticipation by experts in team ball sports (as described in the section above), experts in striking sports also process essential kinematic cues of an opponent more efficiently than nonexperts. Expert anticipation in striking sports seems also to rely on additional and earlier appearing visual cues (e.g. probability information, movement patterns, on-court positioning).

Empirical Findings on Context Information. With respect to the variety of sources of *dynamic* and *stable* context information (see Theories and Models of Anticipation in Sports section above), studies related to this thesis will be presented in the following.

With regard to action tendencies, Mann et al. (2014) examined training effects of accrued knowledge about penalty taker's action tendencies in team-handball goalkeepers. In this video-based experiment, two groups of team-handball goalkeepers watched occluded and unoccluded video sequences of penalty throws from the goalkeeper's perspective on a notebook monitor. One of both groups received constant information as a training intervention about the throwing preferences of some players in the video regarding their throwing side and height, while the other group was available as a comparison group without any provided information. In pre- and post-test, all goalkeepers were asked to predict the throwing directions of the penalty taker via keystroke on a keyboard. It was revealed that the provision of action tendencies of some of the players biased the judgement of throwing directions in terms of congruency effects, what means that the intervention group increased their prediction accuracy for actions of the players with prior tendencies, and decreased their accuracy for those without it.

With regard to coach instructions and tactics, Crognier and Féry (2005) demonstrated in tennis that players are more likely to anticipate an opponent's stroke when they have the opportunity to develop tactical knowledge by imposing their own playing intent. In an in situ experiment on an indoor court, seventeen male tennis players faced different types of on-court conditions with manipulated delivery situations requiring either high (with three prior rallies), moderate (with one stroke towards opponent) or weak (passing shot from opponent) tactical initiative by the players. Each of the situations ended with a passing shot of the opponent, and the players had to intercept the ball with a tennis-specific volley stroke in position close to the net, with occluded vision to restrict kinematic cues of the opponent by using liquid crystal spectacles. It was found that the accuracy of directional motor responses of the ball bounce spot was highest when players were in firm control of their tactical movements (with high tactical initiative).

Decision-Making Behavior and Expertise in Sports

With respect to the approaches to explaining decision making described earlier, an overview of studies will be given in the following in each of the particular decision making approaches.

Empirical Findings on Economic Approach. The *hot-hand* belief is generally related to *economic approaches* in the understanding of human behavior, however, it is also closely linked to the *simple*/*fast and frugal heuristic*s framework in sports (Gigerenzer, 2000, Raab, 2012). Beside the mentioned examinations in the rather isolated penalty kick situations (Bar-

Eli et al., 2007, 2009), the studies of Csapo investigated the *hot hand* phenomenon sport-specifically in open-play situations in basketball.

In detail, Csapo et al. (2015a) aimed for the investigation of optimal defense strategies for *hot* players in terms of perceived streakiness with the application of *fast-and-frugal* heuristics. In this study, he compared the strategic use of heuristic defending between 18 coaches and 20 players from professional playing level in a video-based experiment. Both groups watched video sequences of National Basketball League games showing players with streaky performances in half of the sequences. After each video sequence, the coaches were asked to verbalize a defense strategy for each of the presented situations, and players were asked to imagine to be the ball carrier with options to either pass or shoot the ball. Evaluations of the statements revealed that coaches significantly tended to increase the defensive pressure on perceived *hot* players by making use of *hot-hand*-heuristics, while the player group decided to shoot more often in low-pressure and streaky situations. However, they also decided to pass the ball, regardless of the previous performance, when the defensive pressure increased. Consequently, *hot-hand* phases during a game seem to lift players' performance, nevertheless, these phases appear to be adaptative for players decision-making behavior resulting in rather passing than shooting the ball.

In another basketball study, Csapo et al. (2015b) investigated the same research question as above by using a data-driven approach with additional regard of risk-taking propensity. The authors analyzed 1.216 National Basketball Association games in terms of shot difficulty, a variable calculated with measures of shot distance, shot type and shot angle, and the involvement of conditional probabilities and correlational associations, in order to identify the effect of players' streakiness. The statistical evaluation showed that the three variables significantly affected the shot accuracy, and the longer a successful period of a streak became, the more difficult shots became across all the variables, what illustrates an increasing risk-taking propensity of as *hot* considered players.

Empirical Findings on Cognitive Approach. Especially team sport ball games are a suitable test bed for heuristic research, because team ball sports involve a high-complex and rapidly changing performance environment a player has to cope with. At any time, the challenge for the players is to respond as accurate as possible to uncertain and highly pressurized, time constrained situations.

In team-handball, the examinations of Markus Raab and colleagues often used video-based test settings involving representative team-handball game situations in offense or defense (for details see review of Bonnet et al., 2020). In a *take-the-first* and *take-the-best* study of Johnson and Raab (2007), the experimental setup there contained video sequences of selected attack actions, seen from a ball carrier perspective and presented on a projection board to players with varying team-handball expertise. Similar to the TO condition, each video sequence was stopped at a critical moment of time (e.g. preparation for an action of the ball carrier) and held in a freeze frame for 45 seconds. The participants who have watched the attack sequences in a standing position were asked to verbally report a) the first intuitive decision for an action that came to their mind, b) additional options to decide for, and c) the best of all decisions overall. The quality of decisions was determined by coach ratings who analyzed all solutions that were given by the players a posteriori. The analyses of the players' verbal responses showed that expertise is linked to higher quality of the first generated decision (or option), and players with the highest expertise selected their first option more often as their best choice. The benefit for scientists by using this test method is the traceability of how a final decision was made based on option generation and selection strategies, enhanced by the represented complexity of open-play situations.

Another examination of Raab and Laborde (2011) in team-handball investigated intuitive and deliberative decision-making processes in experts (highest league level of their age group), near-experts (second highest league level of their age group) and nonexperts (third league level of their age group). In this experiment, the authors used the same test setup and methodology from their previous study (Johnson & Raab, 2007). In order to scrutinize decision making and option generation processes, the German version of the PID scale (Preference for Intuition and Deliberation scale; Betsch, 2004), a tool examining preferences for intuitive and deliberative behavior, was filled in by all participants. It was shown that experts were more often correct and faster in their respective choices, and the expert players were also found to be more intuitive than the near-expert and nonexpert players. The results in this study gave support for the *take-the-first* heuristic in decision making in sports, and that expert decision quality seems to be linked to intuitive behavior.

A further expertise study in team-handball investigated the influence of mood (Laborde & Raab, 2013) on heuristic decisions, also with video-based decision scenarios and verbal reports. In soccer, the studies of Musculus and colleagues dealt with the influence of self-efficacy (Musculus, 2018), or developmental aspects (Musculus, Raab et al., 2018) with occluded video sequences presented on a touchpad.

Most recently in team-handball, one study compared the decision-making behavior between team-handball players and novices via selected psychomotor abilities, depending on expertise level, and training seniority (Przednowek et al., 2019). Team-handball players as well as novices underwent psychometric computer tests in a standing position on a touchpad, which consisted of simple reaction time tests, choice reaction time tests, hand-eye coordination tests, and spatial anticipation tests. Surprisingly, novices and team-handball players did not differ in correct responses in the choice response time tests, however, the team-handball players were significantly faster in reaction time (time to initialize the selected response) and movement time (time for dragging the finger to the selected spot). Additionally, the oldest team-handball players within the expert subgroup demonstrated the quickest reaction times in all four tests.

Empirical Findings on Ecological Dynamics. In basketball, Esteves et al. (2011) investigated the posture-related affordances of intermediate basketball players and novices when making a decision in on-field one-on-one situations. Players of both groups were assigned to the role of a defender and an attacker on one side of the basketball court. The experimental task for the attacker was to score by dribbling past the defender and shooting the ball at the basket within a given time frame of 10 s. The defenders' body posture was manipulated by adjusting the position to either a neutral (parallel feet) or diagonal (left or right foot in front) placed defending positions. It was found that the decisions of the attacking players depend on the spatial distance and body posture of the defenders' position. Both player groups demonstrated equal frequencies of decisions to passing the defender on the side where the front foot was positioned, however occurring only when the attacker-defender distance was small. In relation to that, the difference between the experts and novices was that novice attackers were less able to conceal their postural information about their upcoming attack action, whereas the intermediate players conveyed this information better. This was illustrated by rather parallel foot positions of the experts before they initialized their upcoming attack, whereas novice attackers passed the defender on the left side when their own left foot was advanced, and on the right side when their right foot was advanced, therefore providing more information about their upcoming movement direction.

In volleyball, a synthesized work on decision-making expertise involving different test methods was conducted by Afonso, Garganta, McRobert et al. (2012). Their on-field in situ examination showed that highly skilled volleyball players outperformed their skilled counterparts regarding visual search strategies (captured by eye-tracking devices), and condition concepts (recall interviews capturing explanations about under which conditions the type of play occurred) for their individual on-field decisions. The players' performances were assessed while actually acting as backcourt defenders in representative 6 vs. 6 play situations. Although the authors paid less attention on the motor components of the participants, the representative task design in their study revealed insights in cognitive performance advantages of better players.

In tennis, Carvalho et al. (2014) investigated the relative positioning of players on the court and how it constrains their possibilities for a successful action in a visual inspection study (digital match analysis). Against typical measures of response accuracy or response time in studies, the authors developed an empirical function (goal-directed displacement index) that calculated the spatial-temporal relationships between tennis players during a tennis match. By analyzing the players positioning that was tracked with virtual frame-by-frame coordinates (x- and y-axis) during the course of each rally, the authors determined the players' positions in relation to their distance from the central line of the court (*x*-axis), and the center of the net (*y*-axis). Two expert tennis coaches were asked to select a de-stabilizing stroke on the rally interaction of both players expressed by position changes in the coordination system. The overall analysis revealed two different patterns of players' interactions, namely cross and down-the-line rallies, and furthermore, parallel variation (transition from a cross court rally to a down-the-line rally) and angle opening (lateral displacement) were identified to emerge as a break of game dynamics. The results illustrate that perceptual attunements of the opponent's on-court position can be advantageous for players in a rally, because it can foster personal affordances to ultimately increase game pressure on the opponent through successive actions.

To sum up, 50 years of anticipation and decision-making research in sports facilitated the scientific understanding of perceptual-cognitive mechanisms in athletes across many sports domains, outlining that anticipation and decision making play a crucial role when it comes to high-level or elite performance. Different models and theories on anticipation and decision making behavior and expertise were developed and evaluated, aiming to further extend the current knowledge about these special issues. What appears obvious in the regard of the scientific progress in the last decades is that scientific approaches which investigate either kinematic or context information in anticipation, or *ecological dynamics* or *cognitive approaches* in decision making (or a synthesis of both) make use of a broad range of research methods. That appears problematic for the comparability and the evaluation of the obtained findings, since the experimental methods fundamentally underly the quality criteria such as reliability and validity. For this reason, there is an on-going debate in sports psychology about the optimal experimental methods in perceptual-cognitive research, in order to enhance the validity of the data and to foster the interpretation of revealed findings. Elements of this controversy and current developments in science will be introduced in the next section.

Methodological Issues for Assessing Anticipation and Decision Making in Sports

Consequently, in the last two decades, there was an ongoing debate amongst scientists from sports psychology and cognition science about the dissimilarity between unspecific video-based experiments and domain-specific on-field test settings (Abernethy et al., 1993; Araújo et al., 2017; Farrow et al., 2018, Mann et al., 2007, Travassos et al., 2013). A key issue in this debate was that anticipation or decision-making processes underlying expertise could function differently, being subject to the action a player or an athlete is able to realize within the particular test setting (Mann et al., 2013). It is often a challenging endeavor for scientists to design experiments being able to transfer the dynamics and the typical time constraints of play from on-field situations to standardized lab- or field-based experimental conditions (Ericsson & Williams, 2007; Travassos et al., 2013). Important concerns are meanwhile raised in the scientific community about the ecological validity of the obtained findings (Araújo, Passos et al., 2007; Araújo, Hristovski et al., 2017; Mann et al., 2010), since the experimental design requires the consideration of multiple methodological issues for what wants to be measured and explained.

One central aspect in this debate is the choice of the test environment in which athletes supposed to be examined in. The *expert performance approach* (Ericsson & Smith, 1991), aiming to assess the cognitive components of superior performance, outlines that it is essential to develop a representative task environment with sport-specific task constraints, under replicable and standardized conditions in the laboratory and in the field (Ericsson & Williams, 2007). Despite that, there are clear tendencies in perceptual-cognitive experiments for the removal of key elements and environmental constraints from the examined sports domain, such as the spatial and temporal constraints, the dynamically changing situations during play, and the complex cognitive-motor interaction during performance. This could lead to a bias in the performances, as athletes are forced to use strategies in these strategies they would not normally use during open-play situations (Dicks et al., 2009; Williams & Ericsson, 2005).

One the one hand, there is contrary evidence in the literature regarding representative tasks assessing components such as anticipation and decision making best in experiments. In *cognitive approach* experiments it was shown that uncoupled perception-action responses that were given as verbal statements or keystrokes are similar (Farrow et al., 2005), or even more accurate (Huesmann et al., 2021; Ranganathan & Carlton, 2007) than coupled perception-action responses, which required sport-specific action responses from the participants. Another cognitive examination also found that when participants are in a sitting position (static) in computer-based environments, the motor regions of the brain are still linked to the perceptual information picked up (Aglioti et al., 2008). One the other hand, there meanwhile is mounting evidence determining *representative task designs* as the most functional empirical method in expert anticipation and decision-making research to increase the validity of obtained findings, what, among other things, the two meta-analyses by Mann et al. (2007) and Travassos et al. (2013) have revealed.

The Role of Stimulus Presentation and Requisite Responses

The meta-analyses by Mann et al. (2007) aggregated the empirical knowledge about perceptual-cognitive skills and expertise up to that point, also with focus on applied experimental methods. The authors found 42 studies with 388 effect sizes, not only outlining that experts in sports pick up kinematic cues better than nonexperts, measured by response accuracy and time, but also that sport type, research paradigm used, and stimulus presentation significantly moderated the relation of expertise level and perceptual-cognitive skill.

In line with the work of Mann et al. (2007), the comparable meta-analysis by Travassos et al. (2013) put stronger focus on decision-making expertise, identifying different types of *requisite responses* and *stimulus presentation* in the majority of experiments, each with respective sub-conditions. The authors found three prominent sub-conditions for the types of *requisite responses* in the literature: i) verbal reports (oral statements about thoughts in a performance environment), ii) micro-movements (button press, joystick moves, indicated movement), iii) sport-specific motor response (motor action in a sportive environment with task-specific goal). The authors also found three prominent sub-conditions for the types of *stimulus presentation* in the literature: i) slide images (static and two-dimensional projections), ii) video presentations (two-dimensional video sequences), iii) in situ (sport-specific performance environment). Most importantly, the choice of *stimulus presentation* and *requisite responses* are found to be significant moderator variables within the experimental design. A further main point from this quantitative review was that expertise effects are most apparent when the participants actually perform sport-specific motor responses under in situ task constraints, what seems to have the major impact on the moderating variables response time and response accuracy (Travassos et al., 2013). In situ conditions can be set in video simulation settings, as well as in on-field test settings conducted in representative task (natural) environments (Mann et al., 2007; Travassos et al., 2013).

The works of Mann et al. (2007) and Travassos et al. (2013) lead to a stronger awareness in scientists about necessary methodological considerations in perceptual-cognitive research, with respect to reliable and valid performance analyses (Araújo et al., 2017). Based on that, several individual studies from sport practice underpinned the assumptions of the importance of motor components and its interaction with cognitive processes.

The netball study of Bruce et al. (2012), published in *Psychology of Sport and Exercise*, reported that expertise effects regarding response accuracy in passing option tasks significantly differed between a motor skill-execution test (testing for physical passing abilities), a perceptual-cognitive decision-making test (via verbal responses); and a perceptual-motor decision-making test (via motor responses). Additionally, the degrees of response accuracy between all tests also differed within the respective expert groups, indicating that the action abilities of athletes seem to influence *how* a decision is made, but not *what* decision is made.

In soccer, the study of van Maarseveen, Oudejans et al. (2018) compared the anticipation, decision-making and pattern recall performances of skilled soccer players from 3 vs. 3 small-sided games, obtained in video-based decision test and an on-field in situ tests.

Performances of players were measured by experienced soccer coaches, rating the players actions with a notational system. Evaluations of the data showed no correlation between the level of anticipation and decision-making performances between both test conditions, suggesting that cognitive processes run distinctively when action components are involved.

A recent study in team-handball (Huesmann et al., 2021) illustrated that the anticipation of throw directions in penalty situations was more accurate when the intermediate and novice team-handball goalkeepers in this study responded via key press (perception-action artificial condition), instead of a natural movement response (perception-action natural condition). The experts in this study, however, demonstrated superior accuracy performances in the natural test condition, indicating that the disregard of action in experimental designs can bias the actual on-field behavior to be examined.

Current Approaches in Anticipation and Decision-Making Experiments

Among other works, these studies inspired established anticipation and decision-making theories and models to extend their knowledge with respect to the interactions between motor and cognitive system. With respect to the importance of the type of *stimulus presentation* and *requisite responses* and their connected enhancement of test validity, current developments in sports psychology show a merging of rigid theoretical approaches from anticipation and decision-making research. Current models, such as SMART-ER (*Situation Model of Anticipated Response consequences in Tactical decisions – Extended and Revised*) by Raab (2014) or the *embodied-choice* framework by Lepora and Pezzulo (2015) combine elements such as heuristic decision rules from *cognitive approaches* with representative performer environments from the *ecological dynamics* that consider action and perception linkages, by also simultaneously considering the processing of anticipatory information such as cue utilization as well.

Involving anticipatory aspects in decision-making processes, the concept of SMART-ER by Raab (2014) was developed in order to explain time-pressure decisions in sports (e.g., tactical choices of dribbling, passing, or shooting) as a function of top-down and bottom–up interactions of the cognitive and the motor system. Anticipated response consequences are described as "a representation of the sensorimotor system in which we predict future (anticipated) changes in the environment as a consequence of our movements" (Raab, 2014; p. 3). Top-down processes describe a rather cognitive-driven control of sensory actions, such as knowledge about a penalty taker's preferences where to shoot the ball. Bottom-up processes inform the cognitive system about perceived information from the penalty sequence, such as the kickers' foot position towards the ball. These interactions shape the mental representation of an anticipated tactical decision, also depending on expertise and experience (Raab, 2014).

Investigating the effect of sensorimotor interactions on tactical decision-making behavior, one study in team-handball examined expert and near-expert team-handball players in a complex sensorimotor decision-making test (Magnaguagno & Hossner, 2020). The authors created a test scenario consisting of an immersive virtual-reality environment where the players were required to show sport-specific motor responses in an in situ task with occluded 3 vs. 3 defense scenarios. The experts in this study were shown to achieve higher response correctness than near-expert players, assumable due to their anticipatory abilities and level of expertise. Between-group differences in the final positioning of the given motor responses illustrated that it seems important to not only investigate *what* decisions are made by players or athletes but also *how* their decisions are made.

The framework of *embodied choices* (Lepora & Pezzulo, 2015) emerged from the theory of *simple heuristics* (Raab, 2012) which was recently expanded from the related embodied cognition framework (Beilock, 2008), as an integrating and overlapping concept between the *cognitive approach* and *ecological dynamics*. Lepora and Pezzulo define *embodied choices* as choices in which the sensorimotor capacities provide information to guide decision making. It is argued that the human body and its sensorimotor experiences uses sensory- or motor-related cues, for example increasing fatigue and decreasing concentration throughout a game, being considered when selecting an appropriate choice (Raab, 2020).

Some of these cues are referred to cost-value analysis and cognitive evaluations of complex, expected value calculations, but further clarification is needed (Raab, 2020).

One *embodied-choices* study conducted a real-world in situ examination for the assessment of decision-making skills in basketball. Van Maarseveen, Savelsbergh et al. (2018) showed handedness effects in skilled basketball players performing specific 3 vs. 3 pick-and-roll basketball plays as ball carriers. To handle the ball with either the dominant or the non-dominant hand was shown to have significant impact on the types of decisions that were made. Of note, the execution times of correct or incorrect decisions were not significantly different. The identified handedness effect displays how players' decisions can underly body-related constraints, ultimately limiting or enabling the action possibilities and finally resulting in better or worse decisions. Further in situ decision-making examinations within the *embodied-choices* framework do not exist.

To date, the field of sports psychology is broadening its horizon to new approaches in order to explain human behavior in sports. Despite the knowledge gained, so far, the exact mode of operation of anticipatory and decision-making mechanisms, especially why "action, and therefore cognition, is an emergent process under individual, environmental and task constraints" (Araújo et al., 2017, p. 32), still requires more exploration (Araújo et al., 2017; Mann et al., 2007; Travassos et al., 2013). Not only, to generate theoretical knowledge, but also to bridge the gap to best sports practice. To date, the number of studies with recent models in applied sports settings is still rather low. Sport specifically, team-sports was often used for anticipation and decision-making research. Especially, athletes from team-handball were often investigated on anticipation performance in goalkeeping (Cocić et al., 2021, Helm et al., 2020; Loffing & Hagemann, 2014; Loffing, Sölter et al., 2015), or heuristic decision making in offensive game situations (Johnson & Raab, 2007; Laborde & Raab, 2011; Raab & Laborde, 2011, 2013) from a *cognitive approach* perspective. The *ecological dynamics* study of Magnaguagno and Hossner (2020) is the only work that investigated complex, motor behavior in a defensive scenario, other examinations on defensive anticipation and decision-making performance, also with a *cognitive approach*, do not exist. With respect to current developments in sports psychology, this thesis attempts to serve the need for further combined investigations on anticipation and decision-making behavior in team sports with a combined view from a *cognitive approach* and an *ecological dynamics* perspective, with team-handball as the selected sports domain for all experiments in the following chapters 2, 3 and 4.

Aims of this thesis

In a nutshell, the scientific studies provided above highlight the variety of methods used, such as video-based experiments or on-field test, verbal responses, or responses via joystick or touchpad devices, when capturing anticipation and decision making. Despite their discriminating function, significant considerations have to be made in the design of an experiment in order to ensure the ecological validity and interpretation of findings (Araújo et al., 2007; Mann et al., 2010). Especially the type of *stimulus presentation* and *requisite responses* are significant moderator variables when scientists want to assess expertise effects in anticipation and decision making (Mann et al., 2007; Travassos et al., 2013). Current developments in science strongly recommend representative task designs including sport-specific motor responses in a domain-specific performer environment. Despite these facts, there still is a lack of research, in particular in applied team-sports settings, paying attention to recent theories and models in sport psychology and cognition science. The difficulty in the execution of experiments in team-sports is the representation of the complex dynamics of open-play situations, that could explain the low number of investigations (Oliveira et al., 2009). Therefore, reproduceable research is needed to generate valid evidence of why experts are better anticipators and decision makers than non- or near-experts.

The aim of the present thesis is to extend current knowledge of expert anticipation and decision-making behavior and expertise by examining team-handball field players with varying expertise levels in a complex, representative performer environment. Specifically, in a first step, this thesis illustrates the theory-based design of a representative, sensorimotor test with subsequent analyses of its psychometric properties in terms of reproducibility (reliability). In a second and third step, between-group elite-amateur comparisons will be carried out with different methodological approaches in order to investigate the test validity for application possibilities e.g. in future talent identification processes or performance analyses.

In Chapter 2 (study 1), detailed descriptions are made about the procedure of creating a complex, representative anticipation and decision-making test (grounded on the theoretical implications from the literature), capturing multiple sport-specific motor responses from team-handball players. The test scenario consists of temporal occluded video sequences presented on a life-size projection screen in front of a pressure-sensitive contact plate system, showing varying attack actions. Team-handball field players are put into the role of a defender, and participating twice in a test-retest design. By using the level of agreement between motor responses from test retest sessions, the envisaged reliability analyses of the test setting will be conducted. It is expected that the players demonstrate equal decisions in both test sessions, due to the created near-game performance environment and its required decision-making behavior.

Chapter 3 (study 2) will explore the test sensitivity and validity, by comparing the decision-making behavior of an elite and an amateur team-handball player group with the TO paradigm (Jones & Miles, 1978). Both groups will undergo one test session with the identical test setup, as described and used in Chapter 2. Potential expertise effects should be revealed by examining the underlying processes of anticipation and decision making using the variables response frequency and response time. Furthermore, evaluations of response times will deliver additional clarifications, as response (or decision) time is also considered as an important metric of decision making in cognition science (Raab & Laborde, 2011; Ratcliff et al., 2016). It is predicted that the elite player group make different and faster decisions than the amateur player group, based on related works of Raab and Laborde (2011), and Magnaguagno and Hossner (2020) in the team-handball domain.

In Chapter 4 (study 3), the test setting will be modified by the removal of the anticipatory TO paradigm (Jones & Miles, 1978), the video sequences are then presented without visual interruption. Further *expert performance* analyses will be conducted with comparisons of elite and amateur team-handball field players regarding their *specific* and *best choice*, response time and the confidence of the decision. The task for the players is to respond instantly with a motor response on the video sequences, in order to capturing players' decision-making behavior under task-specific constraints with in situ responses, in accordance to *embodied-choice* framework (Lepora & Pezzulo, 2015) within a *simple heuristics* context (Raab, 2012). The rationale for this test manipulation is not only the lack of *embodied-choice* studies in team sports, but also to broaden to recent knowledge in the *embodied-choice* framework. This study contributes to the already highlighted necessity of embodied decision-making experiments (van Maarseven, Oudejans et al., 2018, van Maarseveen, Savelsbergh et al., 2018), since they bear in mind sensorimotor interactions in decision making (Raab, 2014). It is assumed to find equal distinctions in decision making behavior based on the findings in Chapter 3.

In the final Chapter 5, the findings of this thesis will be gathered and recapitulated to provide a condensed form of the gained knowledge. Theoretical as well as practical implications will be derived from the key findings of this work, followed by its limitations and concluded with potential future research directions.

Chapter 2

Reliability of Perceptual-Cognitive Skills in a Complex Laboratory-based Team-Sport Setting

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Abstract

The TO paradigm (Jones & Miles, 1978) is often used in anticipation and decision-making research in sports. Although it is considered as a valid measurement tool, evidence of its reproducibility is lacking but required for future cross-sectional and repeated-measures designs. Moreover, only a few studies on decision making in real-world environments exist. The aims of this chapter are a) implementing a TO test with multiple motor response characteristics, and b) assessing intra- and inter-session item reliability. Temporally occluded videos of attack sequences in a team-handball scenario were created and combined with the SpeedCourt® contact plate system. Participants were instructed to perform pre-specified defense actions in response to the video stimuli presented on a life-size projection screen. Intra- and inter-session (after at least 24 hours) reproducibility of subjects' motor responses was analyzed. Significant Cohen's (0.44 – 0.54) and Fleiss' (0.33 – 0.51) Kappa statistics revealed moderate agreement of motor responses to the majority of attack situations in both intra- and inter-session analyses. Participants made faster choices with more visual information about the opponents unfolding action. The findings indicate reliable decisions in a complex, near-game test environment for team-handball players. The test provides a foundation for future TO studies, including recommendations for new explanatory approaches in cognition research.

Keywords: *temporal occlusion*; *decision making*; *anticipation*; *team-handball*

Introduction

In team sports, players use relevant visual cues of their opponents to score or prevent goals, or simply to position themselves in an advantageous initial situation in attack or defense. Visual information about player positioning (Abernethy et al., 2001; Murphy et al., 2018) or postural cues (North et al., 2016; Runswick et al., 2018; Ward et al., 2002) can be used to anticipate an opponent's intention (Gredin et al., 2019; Helsen & Starkes, 1999; Savelsbergh et al., 2002) and allows for making punctual decisions. To investigate anticipation and decision making in laboratory settings, the TO paradigm (Jones & Miles, 1978) is a well-established paradigm that has been applied in several studies. In TO, action sequences are occluded at different times in order to restrict the visual information available and thus to create varying stages of anticipatory requirements. TO can therefore be used to identify postural cues that influence predictions of future actions or to distinguish better from worse players (Brenton et al., 2016; Causer et al., 2017; Müller et al., 2006). Previous studies using this method have demonstrated that high-skill athletes outperform their low-skill counterparts in response quality, meaning that they pick up less visual information to foresee intended movements in action sequences. A systematic review, conducted by Mann et al. (2007) found an overall expert-novice between-group difference ($p < .001$) for response accuracy with an effect size of 0.25 in 64 selected TO studies. TO was applied as expert-novice paradigm in numerous sport disciplines, for example in volleyball (Loffing, Hagemann et al., 2015; Wright et al., 1990), squash (Abernethy, 1990), badminton (Abernethy & Zawi, 2007), tennis (Tenenbaum et al., 2000), and field-hockey (Starkes, 1987), just to name a few.

Despite the large body of evidence, relevant gaps in TO research include a systematic assessment of test reliability. Even though expert-level comparisons indicate validity, reliability is an equally important psychometric property with direct relevance for applied and basic research on developmental or training-induced changes in decision making. So far, reliability analyses in TO are mostly based on the prediction outcomes of the participants. In volleyball, a cross-sectional study using a computer test with binary choice options (Loffing, Hagemann et al., 2015) investigated the internal consistency of prediction responses in a visual anticipation test. A split-half-technique, using the Spearman–Brown formula, revealed a reliability coefficient for video pair responses of .72. Longitudinal studies in racquet sports demonstrated high inter- (r =.92) and intra-rater-(r =.98) reliability for decision accuracy in cricket (Brenton et al., 2019) or for response accuracy in tennis (r =.90-.96) (Williams et al., 2002) and softball (r =.74 and r =.99) (Gabbett et al., 2007). Here, intra-class correlation was used, and accuracy calculations were executed with interval scaled variables. When considering that the TO paradigm (Jones & Miles, 1978) has been applied in the past 40 years, very limited knowledge about reliability and reproducibility of the paradigm itself exists. Especially the effect of choice of outcome parameter, test design (cross-sectional or longitudinal) or test setup on later interpretations of the obtained findings remains to be questioned.

Moreover, other works with TO examined mainly accuracy outcomes in the form of dichotomous choice options (e.g. ball flight direction or type of throw). In team-handball, especially the 7 m penalty, a rather isolated closed-game situation, was mostly the central object of investigations. Here, a study by Loffing and Hagemann (2014) revealed differences between experienced and novice goalkeepers in anticipating hard or lobbed shots, and accuracy increasing with later occlusion conditions. Results were confirmed in another study by Cocić et al. (2021). The binary outcomes were obtained in computer-based test settings or as a verbal report, and often without a timely restriction. Such lab-based test setups could surely lead to diminished expert advantages but it seems to only partially capture anticipation skills (Mann et al., 2007). While decisive moments of kinematic cues could be identified in penalty throwing, however, decision making under time constraints in complex, representative situations was rarely considered in team-handball so far. In one of a few studies, Williams et al. (2002) noted more rapid decision times of skilled players in a real-world test scenario in tennis. Here, participants had to respond to real-life tennis serve projections by taking a step to one of four pressure sensitive pads and by swinging the racket as if to intercept the ball. As Ratcliff et al. (2016) state in their work, diffusion models could provide further reference points for anticipation and decision making in such multialternative choice assessments. They also emphasize the inclusion of supportive confidence judgements and response times. Investigations dealing with open-game situations in team sports, in which field players face multialternative attack or defense decisions, are strongly lacking. The general importance of sport-specific anticipation measures with near-game tasks and real-size projections is recommended in the given literature (Dicks et al., 2010).

In order to assess perceptual-cognitive skills in team-handball, the experimental setup provides the possibility to circumvent the mentioned deficiencies of TO research. The test setup requires participants to make multiple-choice decisions in typical team-handball defense situations, facing an attacker. A TO test scenario with standardized videos was created, where an elite center backcourt player executes specific attack actions. The defending participants had to decide how to respond to these attacks with predetermined multiple defense actions. Throughout the test scenario the video’s time lengths increased and so the information content in it as well. The distributions of defense actions and its particular motor initialization times was recorded. Initialization times of decision outcomes contribute to a better understanding of anticipatory judgements (Brenton et al., 2016). The multiple-choice character of motor responses in real-world environment offers a genuine reflection of option-generating tasks in team-handball. The main focus of this study is to develop a software-based test scenario and a subsequent quality criteria analysis for intra- and inter-session reliability.

Materials and Methods

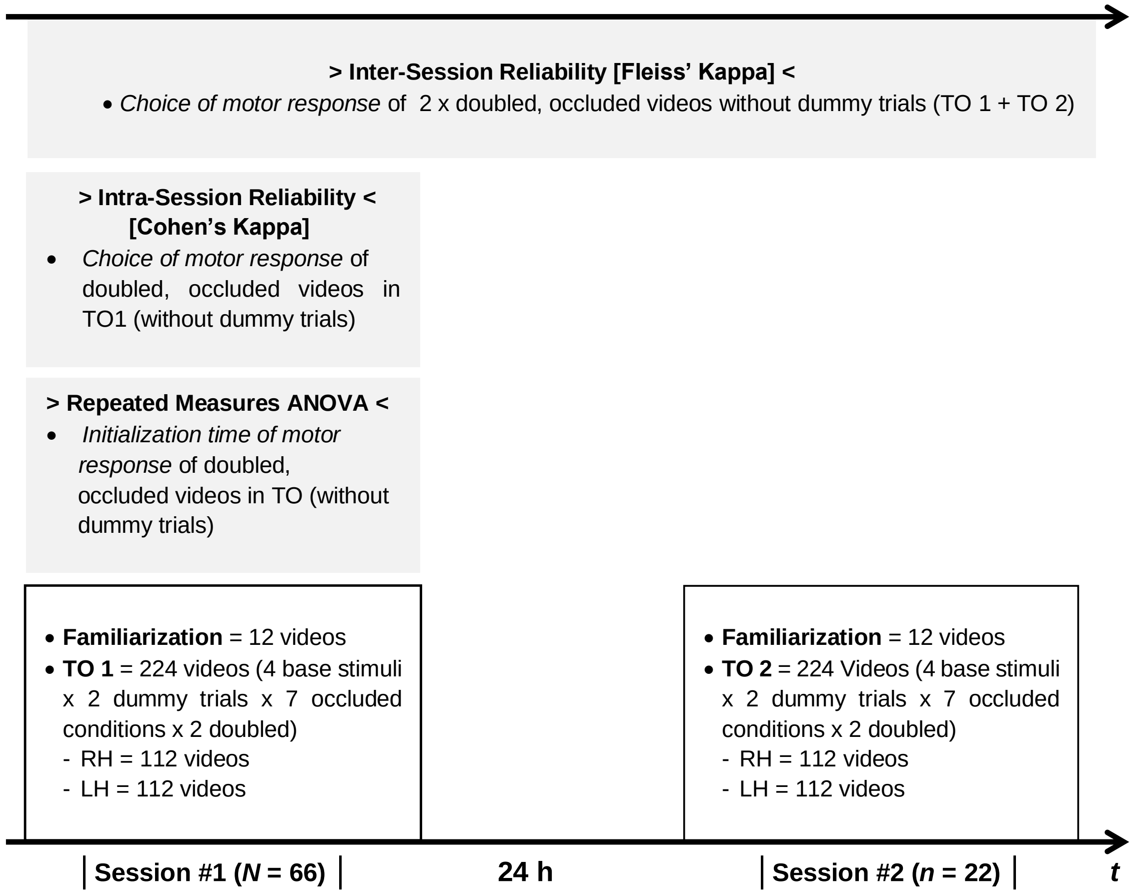


Figure 1.1. Study design and statistical analyses for all measured parameters. *Note.* TO 1 = Temporal Occlusion test scenario 1; TO 2 = Temporal Occlusion test scenario 2; RH = Right-handed attacks; LH = Left-handed attacks.

A detailed overview including the statistical approaches used in the study design is given in Fig. 1.1. With respect to the main aim of this study, reliability analyses in particular, the study is created in a test retest design, with two measurement sessions (session #1, session #2). To evaluate intra-session reliability in TO1 (session #1), the level of agreements of the choice of motor responses in each of the doubled video clips by using Cohen's Kappa was analyzed. Within session #1, further analyses of the initialization time of the motor response choices with repeated measures ANOVA were conducted. The inter-session (session #1 and #2) reliability was evaluated by the level of agreements between the 2 x doubled video clips from TO 1 and TO 2 by the use of Fleiss' Kappa statistics.

Participants and Recruitment

Sample size calculations for the study design at hand revealed that at least 59 participants (with a default 10 % drop-out) were required for analyses with n = 2 videos, a minimally acceptable level of reliability of $p0$ = 0.4 (null hypothesis), p = .05, and β = 0.2 (Walter et al., 1998). Sixty-six male team-handball players (M_{age} = 17.89 years, SD = 7.64 years) from six teams of different age and performance levels (elite under-15; amateur and elite under-17; elite under-19; amateur and elite adult) participated in this study. Four teams (n = 44) belonged to a youth academy of a professional team-handball club of the German Handball Federation. These four teams had six to eight training sessions per week, with one match at the weekend. They all competed in the highest leagues in their respective age group. Therefore, players of these teams can be considered as elite players. Two teams (n = 22) were recruited from the rural and city area of Magdeburg, Germany. They competed on a local level, with two training sessions and one match per week. Players of these two teams can be considered as non-elite players. Testing was carried out in the first half of the team-handball season 2020/21, in October and November. During this time, all championships in every league were running already, that is why all teams had a normal weekly training and match schedule, without being affected or restricted by any local or federal COVID-19 regulations. During the test, participants were instructed to perform with a maximum effort. Injuries led to exclusion of the study. Prior to their participation, all participants and legal guardians were informed about the purpose, risks, and benefits of the study. Participants had to give a written informed consent before the first test day. Participants later were not able to be identified from all test results. The study protocol was approved by the president's office from the Otto-von-Guericke University Magdeburg and the German Federal Institute of Sport Science (IIA1- 070506/19-20). The study was conducted in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

Apparatus and Stimuli

The experimental test setup followed the procedures of Raab (2002). Here, the SpeedCourt® (Q12 PRO mobile, GlobalSpeed, Hemsbach, Germany) system was used, an interactive, cognitive-motor test device. It includes ten contact plates (50 cm x 50 cm) on a platform of 5.25 m x 5.25 m with a life-size projection screen for experimental stimulus application. All plates can either be modularly connected or controlled individually. Signals of each plate were processed if the applied force exceeded 80 N. Due to the contact plate distances of about two meters (for- and backwards from seven to nine meter line, and in both sideways directions from the central plate), the SpeedCourt® covers typical movement ranges of a central defender in team-handball. A set of video clips of individual basic handball attacking actions was produced before the experiment. First, a video script was created with potential team-handball attacks with focus on individual basic and simple actions. In accordance to Müller et al. (2015), four representative tasks were used as an important methodological aspect in the test design: *Breakthrough*, *Pass*, *Standing throw*, and *Jump throw* were filmed considering their key movement characteristics as described by Kromer (2015). A video script provided the basis for subsequent video recordings and included various versions of all four attack actions including a variety of movement executions such as different run-up steps or changing movement directions.

The recordings took place on an official team-handball field with three back players. A high-speed camera (GoPro HERO 6) with a resolution of 25 frames per second was placed on the 7 m penalty line. That position should imitate the central block position in the defense, from a 1.8 m viewing height towards the attacking center back player. The left and right back player were in passive-assistive function as pass-givers, the right-handed center back player was the active performing player. In order to ensure standardization with highest movement quality, the center back player was a new member of a German DKB Handball Bundesliga team and also part of the German under-21 national team (during the championship season 2019/20). This player was presented later in all videos during the measurements. Players' movements were performed as near-game as possible and with realistic dynamics.

Out of the recorded material, all clips were scanned for appropriateness or inclusion criteria. The inclusion criterion was a clear provocation of a defense action, which was feasible and applicable on the SpeedCourt® for future participants. The four final selected attacks for the test scenario were characterized as follows: Breakthrough began with a pass from the right back player to the center back player into a parallel standing position, followed by a fluent deception move with two last steps to the player's right side and a jump throw onto the goal; the Standing throw and the Pass also started with a pass from the right back to the center back player, who immediately executed a three-step run-up with a subsequent throw onto the goal, or a pass to the left side; the Jump throw was executed after the pass from the right side and a two-step run-up. Figure 1.2 illustrates the time-motion sequence of all four attacks. The appropriate defense actions that had to be chosen by the participants later were forward movement/tackling, sideways movements (left/right), passive position/blocking through holding the defense position (Kolodziej, 2013). The assignment of these actions to the respective contact plates is shown in Figure 1.3. Attack actions were excluded that were considered too ambiguous in terms of execution or response. These actions were later used as dummy trial videos to avoid expectation effects in response behavior (Anderson, 1983).

Videos were temporally occluded using *Adobe Premiere Pro CS5*. Visual artefacts were detected and erased (e.g., the pass-givers) that could lead to possible memory effects in the participants. According to the fact that, due to their handedness, left-handers experience greater advantages in the context of anticipation in sports (Loffing & Hagemann et al, 2015; Loffing, Sölter et al., 2015), all clips were horizontally flipped later into left-handed versions. The four attack sequences were temporally occluded within a general time frame of ball was passed to attacker (t_6) and obvious end of attack (t_0), with time intervals of 200 ms (t_6 = -1200 ms; t_5 = -1000 ms; t_4 = -800 ms; t_3 = -600 ms; t_2 = -400 ms; t_1 = -200 ms; t_0 = 0 ms). Finally, every video clip was doubled for the envisaged reliability analyses. 112 videos were created, resulting in a total of 224 video clips when dummy trials are also considered (4 base stimuli x 2 dummy trials x 7 TO conditions x 2 doubled x 2 handedness). This occlusion paradigm enables later explanations about how the amount of postural cues within the attacker's movements affects decision making processes. The duration of each clip was not longer than 2 s (ending at t_0), and videos were sized 1280 x 720 pixels (width x height). The final experimental test scenario was implemented using *Lazarus* (Version 2.0.10), a Delphi compatible cross-platform for rapid application development.

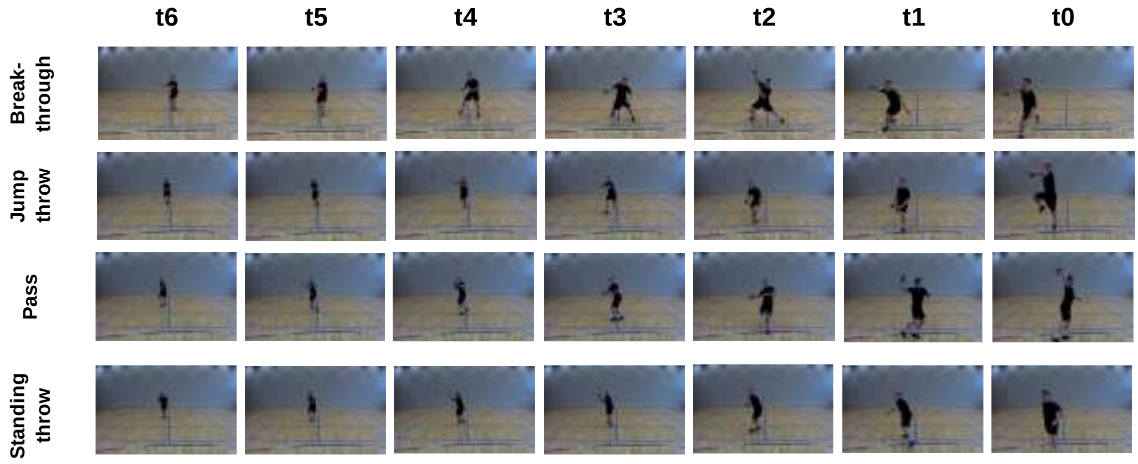


Figure 1.2. Illustration of screenshots of each occlusion time point of the 4 baseline video stimuli, respectively. *Note.* Breakthrough began with a pass from the right back player to the center back player into a parallel standing position, with a fluent deception move and two steps to the player's right side with a throw after single-leg jump. Jump throw was executed after a pass from the right side and a two-step run-up. After caching the ball, the center back player performed the Standing throw or the Pass after a three-step run-up.

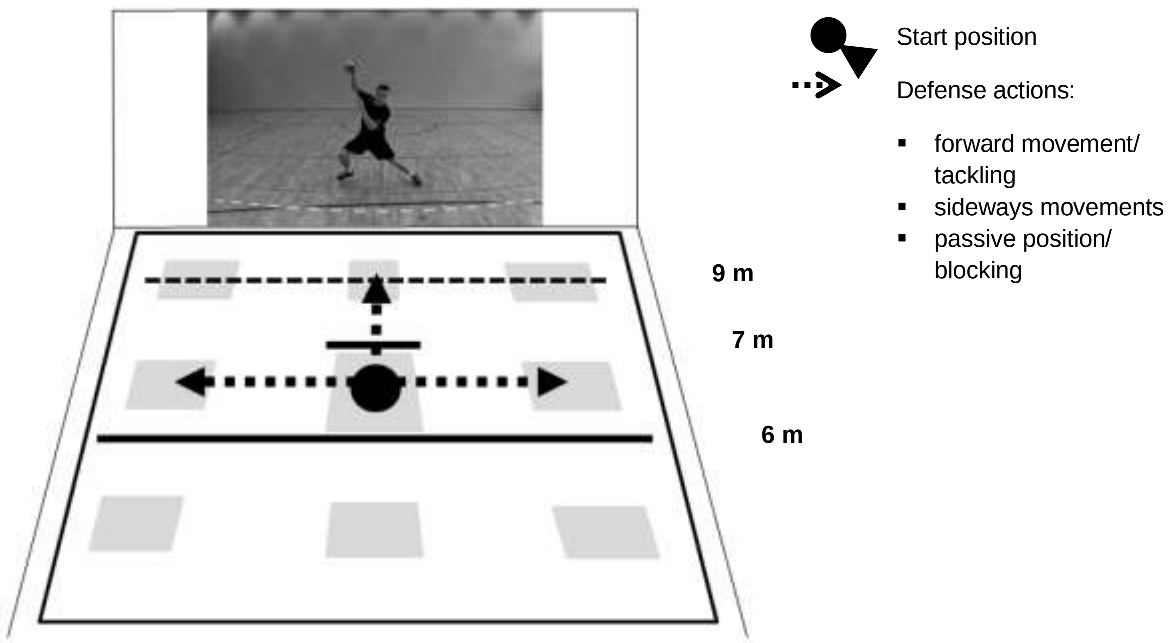


Figure 1.3. Motor responses as defense actions with respective contact plates on the SpeedCourt® in front of the projection screen.

Procedure

In each TO test scenario, participants were tested individually performing in front of a projection screen (3 m width x 2.5 m height). In the test scenario, participants were instructed to give a motor response for every video in form of a team-handball specific defense action. For that, participants had to step onto a predetermined contact plate, for example leaving the central plate to move forward or jump block onto the central plate again. Team-handball field lines were also marked for a game-realistic setup. Participants always started as a center block player in a classic man-to-man defense system, positioned on the 7 m line on the central contact plate (Fig. 1.3). When assuming the starting position, a 3 s countdown appeared on the screen with an attack video following. Participants were instructed to respond as fast as possible after each presentation ended. To create equal conditions for the entire sample, participants were told to imagine having the same body height, body weight, and age as the attacker, and they also used to see themselves in the central block position in the defense. Especially the advice to show a motor response that came to their mind intuitively while watching and before responding after the video, was strongly emphasized during the instructions. Generally, there was no time limit for making a decision, but as fast and near-game as possible. After valid 'defending' of an attack, a 'Ready?' appeared on the screen for signalizing the participant, that the defense action was recorded. A response was valid, when the participant entered another (or again the central) contact plate with a step. After each response, questions about the intuitive tactical choice given were raised regarding its confidence judgements in form of a Six-point Likert-type scale (1 = absolutely ambiguous, 2 = ambiguous, 3 = indecisive, 4 = tendentious, 5 = unambiguous, 6 = absolutely unambiguous). Then, the participant was allowed to head back to the starting position with a new countdown coming. Unintended (e.g. short hop on the central plate before movement) or too early actions were marked from the lab staff and excluded from analyses.

Following the provision of standardized oral instructions, the participants performed ten trials to familiarize themselves with the test setup. A selection of all four attack actions (right-handed) was presented in a randomized order with different occlusion points. A member of the test staff made sure that participants initialized their defense action within the given time frame.

Additional advices were given when responding too early, when the aimed contact plate was not hit adequately or when movements were too hesitant. Due to its team-handball specific nature, participants engaged themselves quickly in the test setting. No further information about the number of videos, the test scenario or the test performance was provided during the subsequent experimental trials. During the experiment, participants always started with the right-handed block, with a 5 min break before continuing with the left-handed block. The TO scenario ran in a structured video clip order, starting with the fewest (t_6) and ending with the most information (t_0). Within every occlusion time condition, the videos were randomized. The test session took about 35 min for a total number of 224 videos. All participants passed both test scenarios with a time lag of at least 24 h between the measurements, but not longer than seven days. For the longitudinal reliability analysis two teams (n = 22) underwent two test sessions.

Data Analysis

Two dependent variables based on the recorded data from the contact plates were considered for statistical analyses. The choice of motor response (CoMR, as multi-categorical variable) was defined as a participant's response to the attacker's action, recorded through contact with one of the four response plates. The initialization time of motor response (ItMR) was defined as the elapsed time (in ms) from the end of the video presentation until the participant left the contact plate (i.e., the applied force falls below 80 N). Note that individual ItMR values exceeding 2.5 times the absolute deviation around the median (calculated according to Leys et al., 2013) were categorized as outliers and therefore discarded from statistical analyses.

Statistical Package for the Social Sciences Version 26 (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. Cohen's Kappa (Cohen, 1960) was used for intra-session reliability of doubled videos for respective agreements of CoMR (session #1). Fleiss' Kappa (Fleiss et al., 2013) was used to assess inter-session reliability of two x doubled videos for agreements of CoMR (session #1 and #2). A 95 % confidence interval was calculated according to Sheskin (2011). Overall Kappas (intra- and inter-session) are presented as a mean of all Kappa values of each occlusion within the hand-specific attack actions, respectively. The interpretation of Kappa coefficients based on the proposed standards for strength of agreement: <0 = poor, 0.01-0.20 = slight, 0.21-0.40 = fair, 0.41-0.60 = moderate, 0.61-0.80 = substantial, and 0.81-1 = almost perfect (Landis & Koch, 1977). For all reliability calculations of CoMR (multi-categorical variables), following the proposed Guidelines for Reporting Reliability and Agreement Studies (GRRAS) of Kottner et al. (2011).

With respect to ItMR, it was of interest whether the expected pattern of faster initialization times in response to videos containing more information was present. After establishing normally distributed data by means of the Kolmogorov-Smirnov test, differences in ItMR as a function of occlusion time point within TO session#1 were assessed with one-way repeated measures ANOVA. Greenhouse-Geisser correction was applied in case of violation of the sphericity assumption (assessed with Mauchly's test). Significance level for all analyses was set to the conventional $p < .05$.

Results

Choice Confidence

Choice confidence in all four attack situations (left- and right-handed; intra-session) was high (M = 4.5 and SD = 0.4 on the 1 to 6 point Likert-type scale, see Fig. 1.4).

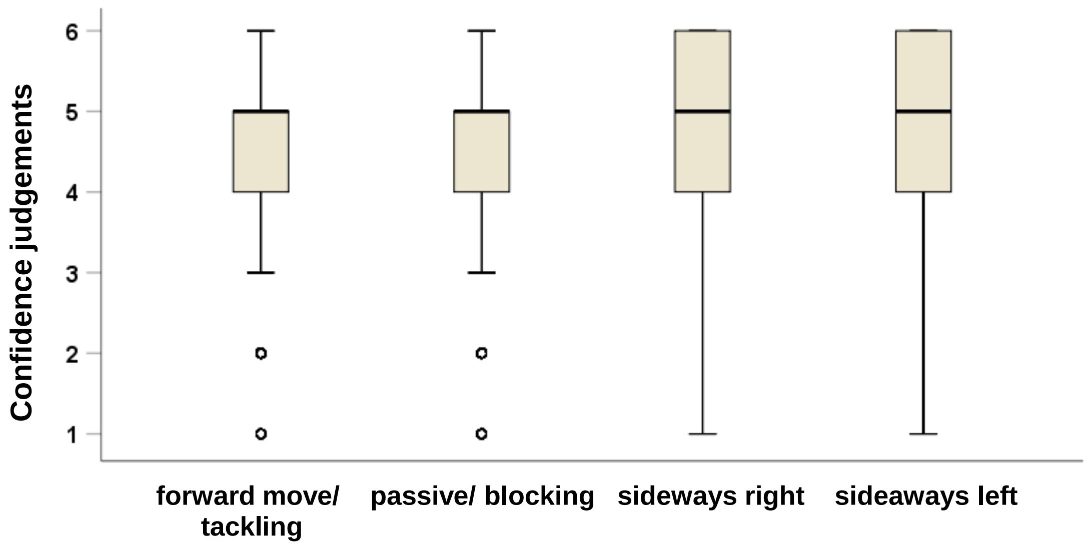


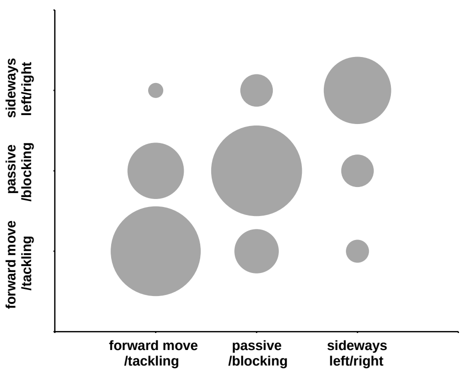
Figure 1.4. Box plots of mean confidence judgements for choice (on Likert-type scale) of motor response for all attack actions (both hands; intra-session). *Note*. 1 = absolutely ambiguous; 2 = ambiguous; 3 = indecisive; 4 = tendentious; 5 = unambiguous; 6 = absolutely unambiguous.

Intra-session Reliability

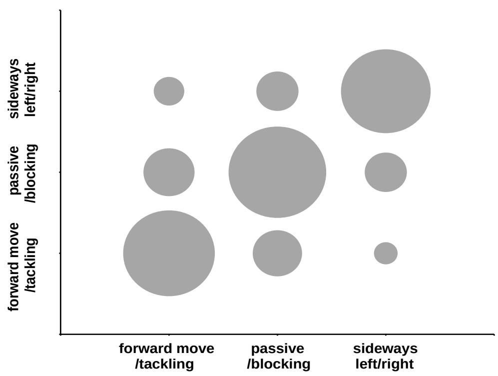
Right-handed Left-handed

Breakthrough

A)



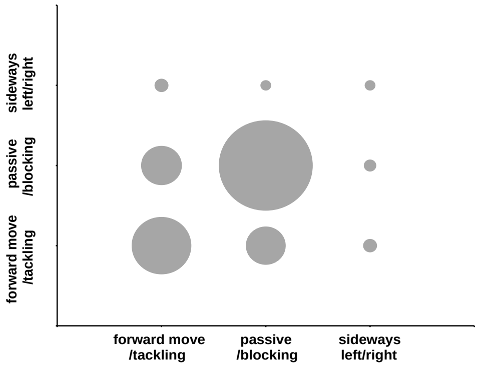
E)

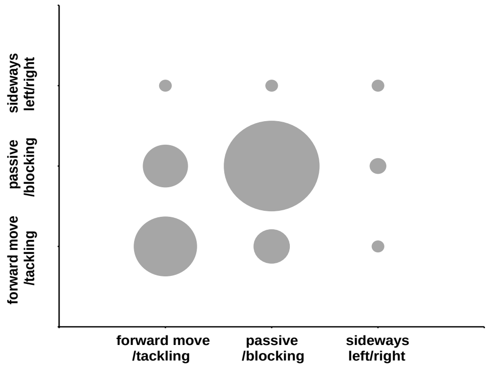


Jump throw

B)

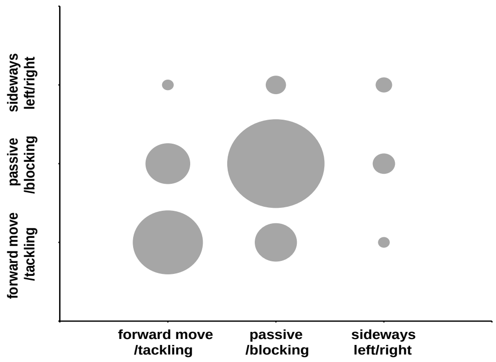
F)



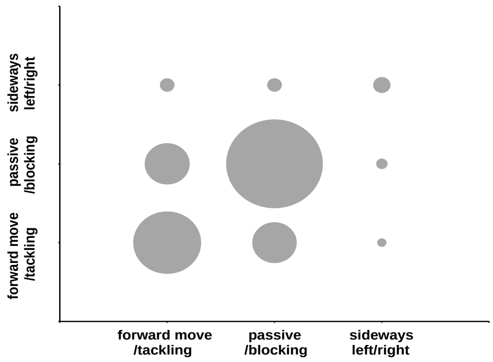


Standing throw

C)

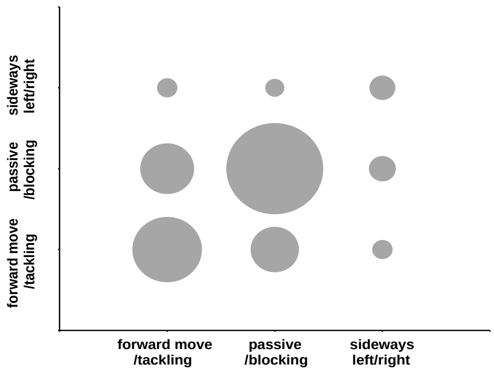


G)



Pass

D)



H)

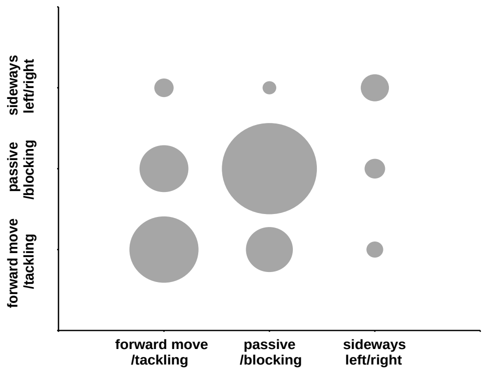


Figure 1.5. Intra-session response distribution and frequency of choices of motor response within video pairs*. Note*. Bubbles show participants' response agreements between first (x-axis) and second video (y-axis) response on all attack actions (sideways left and right as aggregate). Bubble distribution in the right-handed (A – D) and left-handed (E – H) attacks illustrate the response consistency, and bubble sizes represent the frequency of participants' responses. Large bubbles indicate more frequent agreements, small bubbles indicate rather less frequent agreements.

The distribution and frequency of CoMR in session #1 is presented in Figure 1.5. The number of complete CoMR video pairs (intra-session) ranged between n = 44 and 65, from a total of 66 pairs. Missing pairs resulted from the exclusion of videos with invalid motor responses (see Methods). CoMRs at the different occlusion time points can be found in Supplement Material Figure A-D.

A visual inspection of subjects' CoMRs revealed that in most attacks consistent preferences of either a passive position/blocking or moving forward/tackling were present. Furthermore, attacks with less available visual information (t_6 – t_4) were often responded with a forward/tackling choice, while a passive position/blocking response was chosen more often as the amount of visual information (t_3 – t_0) increased. There is a notable difference in the response dynamics in Breakthrough. Decisions in the left-handed version rather tend to sideways right after occlusion time point t_4, whereas participants in the right-handed version preferred passive position/blocking or moving forward/tackling (see Supplementary Material Figure A-D).

Cohen's kappa statistics revealed that intra-session reliability was significant for all actions (all p's ≤ .025; see Tab. 1.1). Agreements ranged from fair (right-handed Pass) to moderate (left-handed Breakthrough). Six substantial agreements were found, four in the Breakthrough and two in the Standing throw action. In occlusion t_6 and t_5, agreements were mostly on moderate agreement levels, followed by a consistent decrease towards chance level (t_5 – t_2), though developing to strongest agreement level at the end of an attack (t_1 – t_0).

The overall mean Kappa agreement of CoMR for individual right- and left-handed attacks can be considered as moderate (Tab. 1.1).

Table 1.1

Intra-session agreements of the CoMR in all right- and left-handed attacks.

		Right-handed attacks				Left-handed attacks			
Attack action	Occlusion	*n*	*K*	95 % CI	*p*	*n*	*K*	95 % CI	*p*
Break-through									
	t6 (-1200 ms)	50	0.413	0.170 - 0.657	0.002	60	0.508	0.295 - 0.721	0.000

	t5 (-1000 ms)	59	0.356	0.145 - 0.567	0.001	59	0.502	0.300 - 0.704	0.000
	t4 (-800 ms)	61	0.506	0.321 - 0.691	0.000	62	0.265	0.095 - 0.436	0.001
	t3 (-600 ms)	56	0.573	0.389 - 0.757	0.000	58	0.600	0.435 - 0.765	0.000
	t2 (-400 ms)	54	0.636	0.463 - 0.808	0.000	54	0.514	0.323 - 0.704	0.000
	t1 (-200 ms)	49	0.681	0.515 - 0.848	0.000	49	0.635	0.456 - 0.815	0.000
	t0 (0 ms)	53	0.552	0.358 - 0.747	0.000	44	0.745	0.576 - 0.915	0.000
	Overall		0.531				0.538		
Jump throw									
	t6 (-1200 ms)	56	0.430	0.212 - 0.648	0.000	63	0.388	0.179 - 0.596	0.000
	t5 (-1000 ms)	61	0.279	0.057 - 0.501	0.013	65	0.476	0.288 - 0.664	0.000
	t4 (-800 ms)	60	0.471	0.261 - 0.681	0.000	62	0.437	0.232 - 0.642	0.000
	t3 (-600 ms)	61	0.517	0.312 - 0.722	0.000	60	0.533	0.335 - 0.732	0.000
	t2 (-400 ms)	62	0.544	0.315 - 0.772	0.000	65	0.455	0.207 - 0.704	0.000
	t1 (-200 ms)	61	0.480	0.172 - 0.787	0.000	63	0.421	0.124 - 0.719	0.000
	t0 (0 ms)	63	0.374	0.076 - 0.672	0.000	58	0.565	0.283 - 0.848	0.000
	Overall		0.442				0.468		
Standing throw									
	t6 (-1200 ms)	59	0.556	0.371 - 0.741	0.000	65	0.489	0.300 - 0.678	0.000
	t5 (-1000 ms)	58	0.534	0.334 - 0.734	0.000	64	0.658	0.484 - 0.833	0.000
	t4 (-800 ms)	61	0.570	0.384 - 0.756	0.000	60	0.452	0.231 - 0.673	0.000
	t3 (-600 ms)	65	0.587	0.398 - 0.776	0.000	64	0.411	0.199 - 0.622	0.000
	t2 (-400 ms)	61	0.346	0.105 - 0.588	0.002	64	0.431	0.199 - 0.663	0.000
	t1 (-200 ms)	64	0.368	0.120 - 0.616	0.002	63	0.437	0.215 - 0.659	0.000
	t0 (0 ms)	63	0.374	0.148 - 0.601	0.001	59	0.641	0.434 - 0.849	0.000
	Overall		0.477				0.503		
Pass									
	t6 (-1200 ms)	58	0.241	0.029 - 0.452	0.025	63	0.340	0.120 - 0.560	0.003
	t5 (-1000 ms)	57	0.344	0.112 - 0.575	0.004	63	0.593	0.399 - 0.788	0.000
	t4 (-800 ms)	65	0.428	0.221 - 0.635	0.000	65	0.378	0.156 - 0.599	0.001
	t3 (-600 ms)	61	0.355	0.122 - 0.587	0.004	65	0.437	0.204 - 0.670	0.000
	t2 (-400 ms)	63	0.336	0.094 - 0.578	0.005	62	0.455	0.221 - 0.688	0.000
	t1 (-200 ms)	61	0.414	0.223 - 0.605	0.000	60	0.485	0.301 - 0.668	0.000
	t0 (0 ms)	60	0.527	0.351 - 0.703	0.000	59	0.423	0.237 - 0.609	0.000
	Overall		0.459				0.490		

Note. Agreements between video pairs (*n*) in each occlusion of an attack (session #1) were assessed using Cohen's Kappa (*K*). Additional 95 % confidence interval (*CI*) and significance values (*p*) are calculated, respectively.

Inter-session Reliability

Results for inter-session reliability (n = 22) can be found in Table 1.2. Agreements of CoMR ranged from fair (left-handed Jump throw) to moderate (right-handed Breakthrough). Only two non-significant, slight agreements were found (right-handed Jump throw at t_3; right-handed Standing throw at t_2). Three left-handed attacks demonstrated substantial agreements in the latest occlusion points (Pass at t_0; Breakthrough at t_0). One almost perfect agreement was found in the left-handed Jump throw.

Overall mean agreement of CoMR for individual right- and left-handed attacks can be considered as fair to moderate. Note the between-hand differences in single Kappa values at t_6 and t_0 in Breakthrough, t_2 - t_0 in Jump throw, t_3 in Standing throw, and at t_0 in Pass, as well as in the overall agreement in Jump throw.

A summarizing graphical overview of within- and between-session reliability results is provided in Figure 1.6.

Table 1.2

Inter-session agreements of the CoMR in all right- and left-handed attacks.

		Right-handed attacks			Left-handed attacks		
Attack action	Occlusion	*K*	95 % CI	*p*	*K*	95 % CI	*p*
Breakthrough							
	t6 (-1200 ms)	0.304	0.120 - 0.487	0.001	0.586	0.415 - 0.756	0.000
	t5 (-1000 ms)	0.268	0.103 - 0.433	0.001	0.338	0.149 - 0.526	0.000
	t4 (-800 ms)	0.408	0.277 - 0.540	0.000	0.302	0.171 - 0.433	0.000
	t3 (-600 ms)	0.416	0.285 - 0.547	0.000	0.522	0.392 - 0.653	0.000
	t2 (-400 ms)	0.551	0.411 - 0.692	0.000	0.418	0.283 - 0.553	0.000
	t1 (-200 ms)	0.592	0.455 - 0.730	0.000	0.609	0.454 - 0.764	0.000
	t0 (0 ms)	0.588	0.425 - 0.750	0.000	0.760	0.573 0.948	0.000
	Overall	0.447			0.505		
Jump throw							
	t6 (-1200 ms)	0.366	0.206 - 0.527	0.000	0.443	0.279 - 0.608	0.000
	t5 (-1000 ms)	0.225	0.053 - 0.398	0.010	0.216	0.059 - 0.374	0.007
	t4 (-800 ms)	0.241	0.077 - 0.404	0.004	0.406	0.236 - 0.577	0.000
	t3 (-600 ms)	0.126	-0.048 - 0.301	0.156	0.299	0.132 - 0.466	0.000
	t2 (-400 ms)	0.351	0.177 - 0.526	0.000	0.608	0.433 - 0.783	0.000
	t1 (-200 ms)	0.497	0.318 - 0.676	0.000	0.671	0.487 - 0.855	0.000

	t0 (0 ms)	0.513	0.339 - 0.688	0.000	0.932	0.732 - 1.132	0.000
	Overall	0.331			0.511		
Standing throw							
	t6 (-1200 ms)	0.587	0.442 - 0.732	0.000	0.423	0.286 - 0.560	0.000
	t5 (-1000 ms)	0.543	0.395 - 0.691	0.000	0.467	0.318 - 0.616	0.000
	t4 (-800 ms)	0.424	0.261 - 0.586	0.000	0.497	0.318 - 0.676	0.000
	t3 (-600 ms)	0.132	-0.038 - 0.303	0.128	0.460	0.291 - 0.629	0.000
	t2 (-400 ms)	0.374	0.208 - 0.541	0.000	0.346	0.171 - 0.520	0.000
	t1 (-200 ms)	0.356	0.187 - 0.524	0.000	0.416	0.244 - 0.588	0.000
	t0 (0 ms)	0.485	0.320 - 0.650	0.000	0.631	0.468 - 0.794	0.000
	Overall	0.415			0.463		
Pass							
	t6 (-1200 ms)	0.382	0.240 - 0.523	0.000	0.431	0.273 - 0.590	0.000
	t5 (-1000 ms)	0.353	0.185 - 0.522	0.000	0.499	0.328 - 0.670	0.000
	t4 (-800 ms)	0.279	0.108 - 0.449	0.001	0.248	0.077 - 0.418	0.004
	t3 (-600 ms)	0.226	0.047 - 0.405	0.013	0.440	0.265 - 0.615	0.000
	t2 (-400 ms)	0.360	0.191 - 0.528	0.000	0.450	0.279 - 0.621	0.000
	t1 (-200 ms)	0.276	0.128 - 0.425	0.000	0.271	0.136 - 0.407	0.000
	t0 (0 ms)	0.295	0.152 - 0.438	0.000	0.624	0.475 - 0.773	0.000
	Overall	0.378			0.477		

Note. Agreements of four responses from 2 video pairs (one pair in each of both sessions) in each occlusion of an attack were assessed using Fleiss's Kappa (*K*). Additional 95 % confidence interval (*CI*) and significance values (*p*) are calculated, respectively.

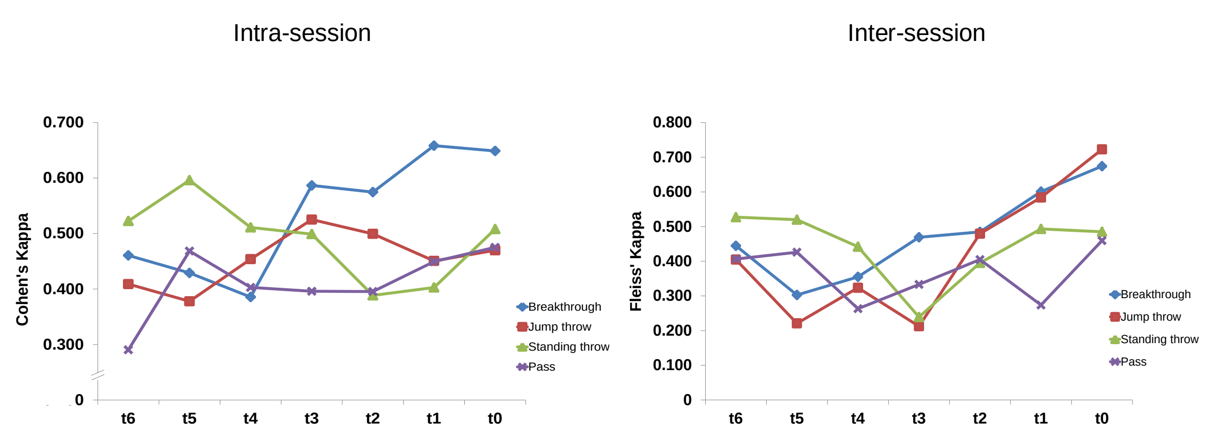
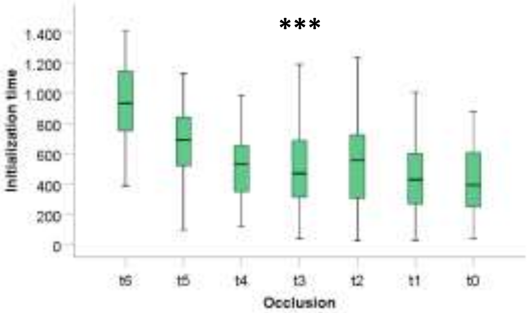


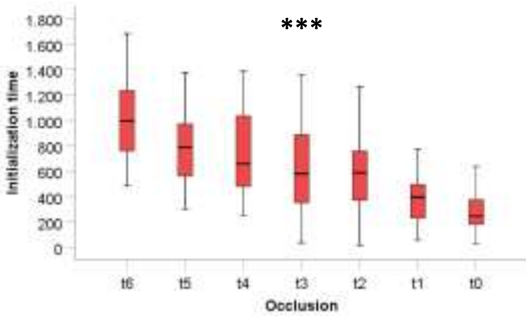
Figure 1.6. Mean Kappa agreements (for both hands) of CoMR in each occlusion in all attack actions (intra- and inter-session).

Initialization Time

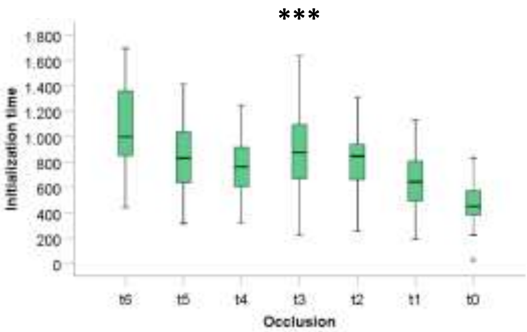
Right-hander	Left-hander

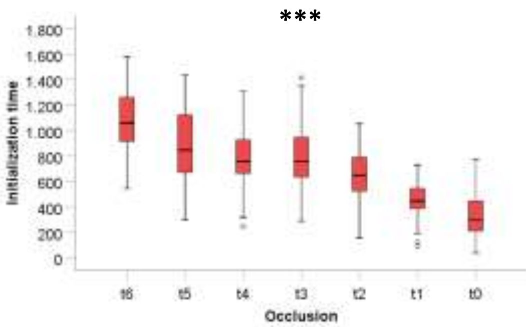
Breakthrough



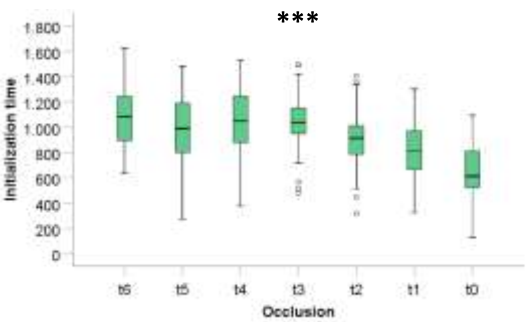


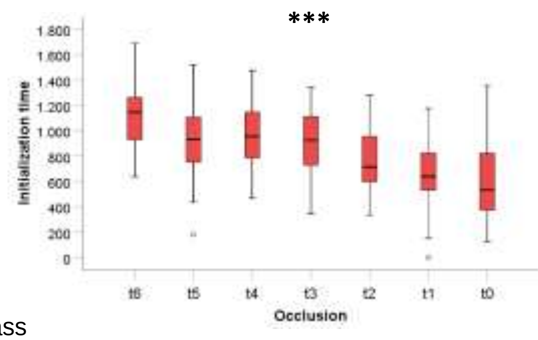
Jump throw





Standing throw





Pass

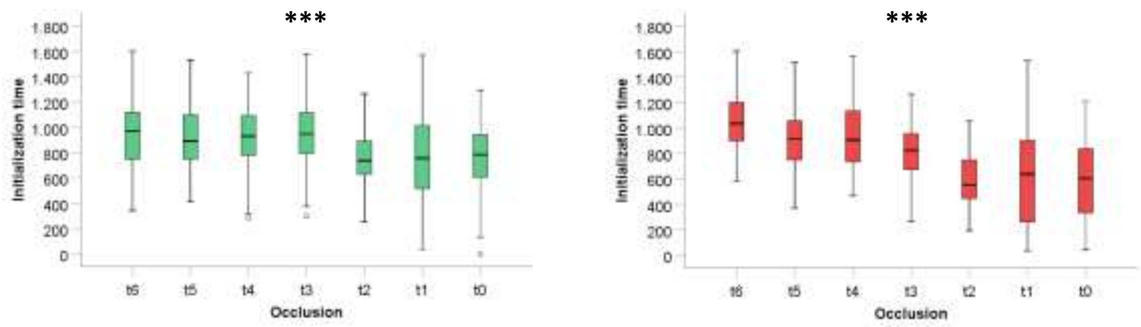


Figure 1.7. Intra-session Initialization times (mean of video pairs in ms) of motor responses for all attacks*. Note*. ***p < .001.

The results for ItMR (Fig. 1.7) show a consistent decrease of movement time with increasing information content. Repeated measures ANOVA revealed significant effects for the occlusion condition in all right- (Breakthrough: $F(4.42,176.64) = 37.72$, $p < .001$, $\eta^2_p = .49$; Jump throw: $F(4.74,246.66) = 43.62$, $p < .001$, $\eta^2_p = .46$; Standing throw: $F(4.11,192.51) = 40.41$, $p < .001$, $\eta^2_p = .46$; Pass: $F(5.06,268.27) = 13.24$, $p < .001$, $\eta^2_p = .20$) and left-handed attacks (Breakthrough: $F(4.17,204.52) = 78.78$, $p < .001$, $\eta^2_p = .62$; Jump throw: $F(4.03,185.15) = 121.14$, $p < .001$, $\eta^2_p = .73$; Standing throw: $F(3.60,201.39) = 65.60$, $p < .001$, $\eta^2_p = .54$; Pass: $F(4.21,206.15) = 63.64$, $p < .001$, $\eta^2_p = .57$). Globally, the fastest response times are found in t_0, the slowest response times in the t_6 videos.

Discussion

The TO paradigm (Jones & Miles, 1978) is considered as a well-established tool to assess perceptual-cognitive skills in sports (Williams & Jackson, 2019b). The aim of the present study was to create and evaluate a real-world like test environment to address perceptual-cognitive skills in team handball. Specifically, in line with recommendations in the literature (Dicks et al., 2010), the test uses a) a life-sized projection screen on a contact plate system, b) varying open-game attack actions from team-handball, and c) multiple motor defense actions. Athletes' self-reports indicated that they responded with a high degree of confidence to the video clips, therefore suggesting that meaningful team-handball-related information was presented. Within- and between-session reliability analyses generally revealed moderate agreements of the motor responses chosen. With increasing visual information about the attackers' unfolding actions, participants more rapidly initiated their defense actions. The results qualify this new test setup for future longitudinal measurements (e.g. in the context of cross-sectional analyses, correlation studies or tactical skill training).

Choice Confidence and Initialization Times

Choices in the test setup were generally rated as tendentious to unambiguous which can be interpreted as evidence for an appropriate task difficulty level within the near-game test environment Also, faster response times with increasing visual information were observed which is consistent with current models of decision making (Ratcliff et al., 2016). Subjects seem to get closer to decision thresholds the more information provoking a certain defense action is accumulated. With temporal progression in the videos, the attacker offers more information about the intended action through an ongoing occurrence of kinematic cues, what apparently lead to facilitated clarifications about the tactical decisions made by the defending participant. The resulting accuracy increase in later occlusion time points are in line with several computer-based TO studies (Farrow et al., 2005; Loffing, Hagemann et al., 2015). Regarding the motor aspect in this study, the results are also in good agreement with the findings of Farrow et al. (2005), where accuracy of decision quality from tennis-specific return strokes improved over occluded time points. Through the overall linear decrease of motor initialization times in the occlusion time course, it seems that motor response times in this TO model are associated with decision making processes and accuracy outcomes. Projected to the one-on-one situation in team-handball, an earlier perception from an attacker's future motion could lead to higher success rates of the defender's actions realized with *embodied choices*.

Following up on the matter of response time, explanatory approaches in team-handball are given by the study of Raab and Laborde (2011). Their video-based experiment demonstrates that expert players make faster and better tactical choices than near-experts and non-expert players. Comparisons of intuitive and deliberative preferences for tactical choices in attack situations were drawn using decision time as a performance-discriminating factor. Supportive for *take-the-first* heuristic (Johnson & Raab, 2003), experts seem to rely on very little information for making a rather intuitive tactical decision, resulting in faster and better choices. Projecting this heuristic model on the obtained findings, the initialization times could be of strong consideration for future intuitive decision-making analyses in complex motor settings. Worthwhile approaches for possible expert-novice comparisons could be provided by the *take-the-first* and *take-the-best* strategies (Gigerenzer et. al., 1999). Generally, using motor initialization times in complex TO settings could also benefit future accuracy outcomes (e.g. through identification of waiting strategies before decision making (Afonso, Garganta, & Mesquita, 2012), or in the context of *embodied choices* (Raab, 2017a).

Intra- and Inter-session Reliability

Reliable measurements constitute a basic prerequisite for reproducible correlational studies, cross-sectional group comparisons, and longitudinal studies (within or between groups) (Hopkins, 2000; Loken & Gelman, 2017). Yet surprisingly, to the best of knowledge, no study to date systematically investigated the reliability of multiple-choice performance metrics in TO research.

Cross-sectional studies revealed some evidence for reliability in the TO paradigm (Jones & Miles, 1978) in team-sports. Internal consistency analysis of a computer-based TO test in volleyball, where participants had to distinguish between smash and lob, found acceptable reliability (r =.72) for video pair responses on interval scale level (Loffing, Hagemann et al., 2015). When novices (no experience in competitive volleyball) and skilled volleyball players were separately analyzed, coefficients decreased to .66 and .55, respectively. Generally, with respect to intra-session reliability, moderate-to-substantial response consistency (right- and left-handed) in all occlusion time points evaluated were found. Therefore, besides one exception (Pass), reliability estimates reported here were comparable to the Loffing, Hagemann et al. study (2015).

A closer look at the data revealed attack-specific differences in terms of reliability, which emphasizes the specificity of varying open-game situations. For example, in Breakthrough, the late occluded videos (t_3; t_2; t_1) revealed relatively high levels of agreements. In these occlusions, the full action intention of the attacker seemed to be terminated due to a highly dynamic run-up (t_0 till t_1) and a deception movement at t_3, which is why most participants just reacted subconsciously in the following occlusions (t_4 till t_6) with most likely identical decisions. That may explain the visible rise of the level of agreement in Breakthrough. A further example for necessity of varying game-situations is given by the different distinctions of reliability between right- and left-handed Jump throw attacks (inter-session). Higher left-hander reliability in later occlusion points (t_4 – t_0) could be traced back to a different defense behavior based on greater uncertainty, of how to defend a left-handed player. In fact, left-handed players in team-handball are less frequently represented in team-handball (Loffing, Sölter et al., 2015), which leads to divergent level of agreements.

Similar to within-session reliability, there are only a few longitudinal studies that report between-session reliability. Without a TO approach, a related study of Raab and Johnson (2007) assessed long-term reliability in the context of option-generating research in team-handball. Over a 2-year measurement period, their experimental setup contained full video clip presentations of competition-like attack situations, with the perspective of an attacker onto the defense line. After the end of each video clip (frozen video frame) participants were instructed to verbally report generated options of the player in possession of the ball. Reliability estimations for decision quality within four measurement points were calculated using the split-half test. Spearman-Brown coefficients for quality of the first option ranged from .49 in test wave one to .89 in test wave two. The variability of response reliability in their analyses can be compared to the distinctions of the inter-session Kappa values, ranging between fair and substantial. Recommendations by the authors about further longitudinal studies in heuristic settings in sports were given as well. Other investigations with the TO paradigm (Jones & Miles, 1978), executed in cricket, tennis and softball, found overall high reliability (r = .74 – .99) for decision and response accuracy (Brenton et al., 2019; Gabbett et al., 2007; Williams et al., 2002). Probably, the high reproducibility reported in these studies can be explained by the close-game character of test setups (batting in softball and cricket; tennis serve), with accuracy outcomes consisting of binary predictions of ball flight directions of type of throw. In this study, response agreements ranging from fair to substantial were found. A possible explanation for the fact that agreement in this study was slightly worse compared to the racquet sports studies is that this study used a complex test environment in combination with multiple-choice (instead of binary) response outcomes.

A detailed view on inter-session agreement data reveals that the highest Kappa values occur in the earliest or latest occlusions. This provides margins for interpretative patterns about either easier or more difficult tactical decisions to make at these time points. High Kappa values can be explained by the participants' full knowledge about the attacker's intention in the video clips, especially in the late occlusions at the end of an attack sequence. High Kappa values in the earliest occlusions seem to suggest that too few kinematic cues in the video clips were given for an early and risky defensive intervention by the participant. Few information at the beginning of an attack seem to rather excluded certain response options, such as sideways movements for example, within the decision-making process. The exclusion of options increases the response probability for the options that are left, and so the chance to identify the appropriate option at the same time. Based on a more concentrated number of the likelihood of responses, the Kappa agreements increase. The comparably low Kappas later in the ongoing attack ($t_5 - t_3$) seem to suggest that the amount of kinematic cues in the attackers' movements reached an oversupplying limit in the participants' decision making, shifting from intuitive to rather deliberative. In particular, these time points are suspected to be crucial for the perceptual-cognitive skills based on anticipatory information pick-up.

A number of potential limitations of the findings have to be outlined.

First, Breakthrough showed a disproportionally large number of missing video pairs that can be explained by the high frequency of dynamic kinematic information (e.g. through the attackers' deceptive move). Here, defenders were rather 'dragged' from the attacker's postural changes that lead to habitually premature movement initializations.

Second, the choice of defense actions was governed by the doubled but randomized video clip presentation within occlusion conditions. As mentioned before, Standing throw and

Pass as well as Jump throw and Breakthrough demonstrated similar movement patterns and run-up steps, respectively. Subconsciously, participants could have been aware of previously observed kinematic cues of equal video clips. Previously primed tactical decision for other attacks could thereof result. This problem can be counteracted with the high amount of video clips (224 videos per subject) and the inclusion of dummy trials in the test paradigm.

Third, although degrees-of-freedom of defender's movements were exceptionally high compared to previous studies (Brenton et al., 2019; Cocić et al., 2021; Gabbett et al., 2007; Loffing, Hagemann et al., 2015; Williams et al., 2002), the pre-specified contact plate positions of the test set-up constrained defenders' movement paths. Defending a one-on-one situation in team-handball implies varying body and arm positions that also lie between or off the prescribed contact plates. Therefore, only full-body changes of defender position could be analyzed. Nevertheless, the execution of an additional offensive block requires an initial position changing movement. Staying passive or blocking could not be distinguished too, but again, the positioning in the defense is the main focus. That is why valid insights into tactical defense behavior with this setup are to be expected.

Fourth, in team-handball, the so called 'show-up' is a typical behavior of defenders. 'Show-ups' provoke movement changes or discontinuations of an attacker through disconcertion. A show up normally implies a fast and single step forward up to 8 m, with a fast pacing movement backwards. Other defenders rather prefer a slight offensive position in the defense at 8 m, and not on the classically instructed 7 m line as required in the present study. Additional contact plates at 8 m and between central and lateral contact plates would broaden the space for defense actions and allow analyses of so-called triangle movements (show-up with lateral move backwards in direction to the ball side).

Fifth, the TO paradigm (Jones & Miles, 1978) by nature presents simple time frames with varying postural cues, but the paradigm used here is unable to provide a clear identification of cues' decisive contribution in action sequences. Additional spatial occlusion and eye movement registrations (Morris-Binelli & Müller, 2017) could deliver combined knowledge about what areas or cues in a visual search field are of significant importance for anticipatory processes and provide information about an athletes' information pick-up strategy.

The test battery forms a basis for new entry points to future anticipation research in real-life environments in team-handball, and overall invasive sports. The rarely been regarded but crucial aspect of contextual information or situational probabilities (Loffing & Cañal-Bruland, 2017; Williams & Jackson, 2019a) offer fruitful research perspectives in the context of this new test setup. Due to the main focus on reliability in this paper and the motor character of the experimental setup, these factors are not applicable for explanatory approaches of present findings in this study so far. Nevertheless, it must be mentioned, that with involvements of these factors, the test battery can lay the foundation for more holistic clarifications in cognition in team sports. Due to its now proven reliable properties, the test setup could be used as a motor tool for modified perceptual training (Hadlow et al., 2018) in the future. With further developments and adjustments, it can allow athletes to improve visual information pick-up with repeating natural skill executions in a discipline-specific way. Other areas of interest could be the team-handball defender's anticipation with distinctive situational information in the videos, for example change of court position of the attacker (see Cañal-Bruland & Mann, 2015). How will tactical decisions change, when the two back players perform attack-specific actions at the same time? Brenton and Müller (2018) also recommend the presentation of different protagonists in video-based testings.

In sum, this chapter illustrated the design and evaluation of cognitive-motor test to assess anticipation in team-handball. After using the anticipatory TO method in cross-sectional and longitudinal investigations, the designed cognitive-motor test can be considered as a reliable measurement tool for the diagnose and evaluation of anticipation skills. The statistical inspection of the psychometric test properties found fair to moderate agreements of multiple-choice defense responses, with obvious tendencies to substantial and excellent agreements. Also, feasibility is demonstrated for the combination of the TO paradigm (Jones & Miles, 1978) with team-handball specific motor responses on a test battery. The team-handball specific nature of the test battery, including a reliable anticipation test method (TO) in a real-life inspired decision-making setting, can contribute not only to improvements in cognitive study designs and interpretations, but also to a deeper understanding of cognitive mechanisms in team-handball. As psychological abilities are claimed to be one of the most momentous performance prerequisites in team-handball (Groeger et al., 2019), the experimental test offers possibilities not only for visuomotor training interventions but also for talent identification and talent development processes in team-handball.

Chapter 3

Differences in Decision-Making Behavior between Elite and Amateur Team-Handball Players in a Near-Game Test Situation

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Abstract

Athletic features distinguishing experts from non-experts in team sports are relevant for performance analyses, talent identification and successful training. In this respect, perceptual-cognitive factors like decision making have been proposed to be important predictors of talent but, however, assessing decision making in team sports remains a challenging endeavor. In particular, it is now known that decisions expressed by verbal reports or micro-movements in the laboratory differ from those actually made in on-field situations in play. To address this point, the aim of the following chapter is to compare elite and amateur players' decision-making behavior in a near-game test environment including sport-specific sensorimotor responses. Team-handball players (N = 44) were asked to respond as quickly as possible to representative, temporally occluded attack sequences in a team-handball specific defense environment on a contact plate system. Specifically, participants had to choose and perform the most appropriate out of four prespecified, defense response actions. The frequency of responses and decision time were used as dependent variables representing decision-making behavior. Elite players were found to respond significantly more often with offensive responses ($p < .05$, odds ratios: 2.76 - 3.00) in left-handed attack sequences. Decision time decreased with increasing visual information, but no expertise effect was found. Assumably, expertise-related knowledge and processing of kinematic information led to distinct decision-making behavior between elite and amateur players, evoked in a domain-specific and near-game test setting. Results also indicate that the quality of a decision might be of higher relevance than the required time to decide. Findings illustrate application opportunities in the context of performance analyses and talent identification processes.

Keywords: *sensorimotor decisions, expertise, decision time, motor responses, perceptual-cognitive skills*

Introduction

Features that set apart the sports experts from the non-experts have been a topic of considerable research efforts during the last years. In this regard, it has been proposed that physical (e.g., anthropometric), physiological, psychological, sociological, technical and tactical factors discriminate between athletes of different levels of expertise (Burgess & Naughton, 2010; Piggott et al., 2020; Sarmento et al., 2018). Most emphasis in research has been placed on studying physical aspects and biomotor abilities (such as speed, strength, power, agility, endurance), although recent studies suggest that the predictive validity of these factors regarding performance and talent identification is limited, especially when they are looked at in isolation (Bennett et al., 2018; Bergkamp et al., 2019; Wagner et al., 2016, 2019, 2020). This might be due to the fact that these particular predictors are not representative enough with respect to the contextual constraints of on-field behavior (Bergkamp et al., 2019). To overcome this problem, multidisciplinary approaches have been suggested to diagnose future performance and talent. Particularly, the need to focus more on the psychological and perceptual-cognitive components of athletes has been highlighted in recent studies (Bangsbo, 2015; Bennett et al., 2018; Bergkamp et al., 2019; Piggott et al., 2020; Sherwood et al., 2019, Woods et al., 2016). Indeed, mounting evidence suggests that perceptual-cognitive skills such as decision making constitute a performance-discriminating component in team-sports (Ashford et al., 2021; Mann et al., 2007; Silva et al., 2020; Travassos et al., 2013).

It is against this background that the development and evaluation of tests to diagnose perceptual-cognitive skills and expertise in athletes has gained more and more attention in the last years. A commonly used approach to study sport-specific decision making is the so called TO paradigm (Jones & Miles, 1978). Essentially, studying decision making with this approach involves presenting video clips of selected game sequences on a screen, and subjects watch these clips while usually being in a sitting or standing position (Travassos et al., 2013, for details). After the end of the video sequences, subjects are mostly required to verbalize their intended response for the game situation in question, or to verbalize their generated options

(Johnson & Raab, 2003; Raab & Johnson, 2007; Raab & Laborde, 2011). Decision making in real life evolves from a complex and uncertain context (especially in team-sports), requiring athletes to constantly process information while acting under time and information constraints (Kinrade et al., 2015; Travassos et al., 2012). Against this background, it appears problematic to not consider the specific environment in which the players actually perform, and particularly to neglect the impact of sensorimotor interactions in decision making (Burk et al., 2014; Raab, 2014). Recent examinations in netball (Bruce et al., 2012), and soccer (van Maarseveen, Oudejans et al., 2018) clearly suggest that the decision-making performance in perceptual-cognitive tests (using verbal reports, button press, or micro-movements) differs from actual real-world decision-making performances, thus hampering the ecological validity of findings (Araújo et al., 2007; Ashford et al., 2021). Taken together, these studies highlight that assessing verbal or micro-movement responses (Travassos et al., 2013) might be not sufficient to predict on-field performance, let alone to detect talents. Notwithstanding, there is also evidence in perceptual-cognitive research which showed that uncoupled perception-action responses, given either verbally or by keystroke, are similar (Farrow et al., 2005) or even more accurate (Ranganathan & Carlton, 2007) than coupled perception-action responses, requiring sport-specific action responses. It was also found that when observers are static in computer-based experiments, the motor regions of the brain are still linked to the perceptual information picked up (Aglioti et al., 2008). In team-handball, Huesmann et al. (2021) compared the anticipation performances of advanced, intermediate, and novice team-handball goalkeepers in a perception-action artificial (verbal responses) and simulated (motor responses) condition with. The authors revealed overall superior performances (higher prediction accuracies) in the artificial, verbal response condition, outlining that the evidence regarding the necessity of the involvement of motor components seems mixed. However, when capturing expert performance in decision making, expertise effects are most pronounced when the participants actually performed actions under in situ task constraints (Travassos et al., 2013) in realistic test paradigms under field conditions (Mann et al., 2007).

Since the discrepancy between decision making in decoupled vs. coupled processes of perception and action in task designs has only recently become known, there are only a few studies assessing decision making in near-game test conditions with requirements to perform a sport action (Travassos et al., 2013). One notable example is the study by Magnaguagno and Hossner (2020) in team-handball, which investigated decision making in a performer environment by using virtual reality. Specifically, Magnaguagno and Hossner (2020) presented 1 vs. 1 video sequences between a defending teammate and a left or right back attacker, respectively, ending in either a successful or a lost defense action of the teammate. The participants were put into an assisting role as a defender next to the 1 vs. 1 situation. Depending on the teammates' either weak or strong defending behavior, participants had to decide (based on their anticipatory performance) whether to move sideways for tackling the attacker (in case the weak teammate has lost his duel), or whether to stay in the passive position (in case the strong teammate successfully defended the attacker). The authors found expertise effects in response correctness, showing that expert players responded more appropriately on a lost 1 vs. 1 duel of the respective defending teammate than the near-expert players. However, response correctness simply based on the decision whether to stay passive or to tackle. Further options for defense actions, e.g. provoked by additional varying attack sequences, were not regarded. Also, the respective time of responses (decision time) was not recorded, even though decision time is thought to be an important metric of decision making (Raab & Laborde, 2011; Ratcliff et al., 2016; Seale-Carlisle et al., 2019; Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007; Vaeyens, Lenoir, Williams, & Philippaerts, 2007).

The present study investigated whether decision-making in a near-game performer environment would differ between expert and near-expert athletes. To this end, a team-handball specific sensorimotor decision-making task with varying attack sequences was used, based on the anticipatory TO approach (for details see Jones & Miles, 1978). Previously, it was shown that this test setup is sufficiently reliable to study decision making (Hinz et al., 2021), and by comparing expert vs. near-expert players, now the next step to discover the potential usefulness of this test to distinguish expert vs. non-expert performance will be taken.

This test setup involves both domain-specific motor responses (as compared to, for example, button press) and the opportunity to choose among various response options (as compared to 'either-or decision making'). Decision times were also recorded which allowed to study whether expert and near-expert players would initiate a different defense action (e.g., a 'proactive' behavior like tackling vs. a 'passive' behavior like blocking) in response to identical visual information, and whether there are differences in the accompanying decision times. In order to use representative task constraints (Travassos et al., 2013), the decision-making performances in right- as well as left-hander attack sequences were also investigated, due to handedness advantages in favor of left-handers in sport (Hagemann, 2009; Loffing, Hagemann et al., 2015; Loffing, Sölter et al., 2015).

Materials and Methods

Carrying out between-group comparisons with multiple choices for responses entails difficulties in estimating a priori effect sizes. Therefore, the sample size recruitment complied with sub-sample sizes from earlier between group investigations in this field (e.g. Bruce et al., 2012; Raab & Johnson, 2007; Zoudji et al., 2010).

The sample of participants consisted of 44 male team-handball players (M_{age} = 19.11 yrs.; *SD* = 6.56 yrs.). Two teams (*n* = 22; M_{age} = 17.59 yrs., *SD* = 3.67 yrs.) were recruited of a professional youth academy of a first league team-handball club of the German Handball Federation. All players competed in the highest possible league within their age category. Players of these teams performed a minimum of 14 hours training per week with one competition match at weekends. All players practiced team-handball for at least 8 years. Based on the recommendations of Swann et al. (2015) how to classify expertise level in sports science, players of the two teams can be considered as elite level players. The players of the other two teams (*n* = 22; M_{age} = 20.71, *SD* = 8.54) were recruited from non-professional, local league teams within their age categories. All players performed 4 hours of training per week with one competition match at weekends, and players practiced team-handball between 2 and 22 years. According to the definition of Room (2010, p. 7), who defines a player, 'who takes part in sport for pleasure, as distinct from a paid professional' as amateur player, the players of these two teams can be considered as amateur level players. Differences in age between both groups were not significant (p = .952)

The experiment was conducted during the first half of the championship season 2020/21, in October and November. At that time, all teams had a normal weekly training and match schedule, without being affected or restricted by any local or federal COVID-19 regulations. During the test, participants were instructed to perform with a maximum effort. Injuries lead to exclusion of the study. Prior to their participation, all participants and legal guardians were informed about the purpose, risks, and benefits of the study. All participants had to give a written informed consent before the first test day. Participants were not identifiable from the test results. The study protocol was approved by the local ethics committee from the Otto-von-Guericke University Magdeburg and met the requirements of the Declaration of Helsinki and its later amendments.

All tests were conducted on the contact plate system SpeedCourt® (Q12 PRO mobile, GlobalSpeed, Hemsbach, Germany) which enables sport-specific motor responses to temporally occluded videos. As a basis for profound interpretations of envisaged results, the test setup from a previous study (Hinz et al., 2021) was used, which was introduced and checked for basic psychometric properties (reliability), using four team-handball specific attack actions for intra- (cross-sectional) and inter-session (longitudinal) agreement of the motor response choices and times. Significant Cohen's (0.44 – 0.54) and Fleiss' (0.33 – 0.51) kappa statistics (Fleiss & Cohen, 1973) revealed moderate agreement level of motor responses. Please refer to this paper for detailed explanations regarding test construction and item analyses. In the study at hand, the identical test setup and video stimuli were used, along with the same mapping of the four choice responses (forward/tackling response; sideways left or right movements; blocking/passive behavior) to the contact plates on the SpeedCourt®.

The experimental scenario consists of *Breakthrough*, *Standing throw*, *Jump throw*, and *Pass* videos, which were temporally occluded within a general time frame of *ball was passed* *to attacker* (t_6) and *obvious end of attack* (t_0), with time intervals of 200 ms (t_6 = -1200 ms, t_5 = -1000 ms, t_4 = -800 ms, t_3 = -600 ms, t_2 = -400 ms, t_1 = -200 ms, t_0 = 0 ms). The duration of each video clip was not longer than 2 s (stopping at t_0). Dummy trial videos, showing too ambiguous attack actions for an appropriate defence response, were included in the test scenario, aiming at avoiding expectation effects in response behaviour (Anderson, 1983). Due to handedness advantages in favour of left-handers in sport (Hagemann, 2009; Loffing, Hagemann et al., 2015; Loffing, Sölter et al., 2015), all video clips were mirrored.

The videos were sized 1280 x 720 pixels (width x height) and the test scenario was implemented by using *Lazarus* (Version 2.0.10) software. In total, 112 right- and left-handed attack video clips were presented to the subjects during the measurement procedures.

The test procedure always started on the marked 7 m line on the central contact plate of the SpeedCourt®. In this starting position, a 3 s countdown appeared on the screen, followed by a video stimulus showing an attack action. The aim was to respond as intuitive and as realistic as possible after the video presentation ended. Subjects were then returned to the starting position to prepare for the next countdown. Subjects were instructed that the motor response to a video stimulus should replicate their first intuition for a defence response that came to their mind while watching the video. Too early or unintended given responses were marked for later exclusion. No information about decision performance or the remaining number of videos was provided to the subjects.

In relation to the Bayesian integration framework (Gredin et al., 2020; Vilares & Kording, 2011), all subjects received the same team-handball specific instructions (*stable priors*) about the attacker's action tendencies, the defence tactics, and the match status. *Stable context priors* via action tendencies were provided, meaning that the center back player in the video can be considered as an allrounder or playmaker, being able to put high pressure on the defense through a variety of long and near range standing and jump throws, strong one-on-one actions, and high-quality passing. Tactical *priors* were also supplied to the subjects. More specifically, they were instructed to put themselves in the position of the central block defender in a classic man-to-man defense without teammates, or other opponents than the attacker in the video/situation. The match status was pre-specified as the 50th minute of play (of 60 min in total) and the game score was tied.

Following the instructions, subjects performed ten familiarization trials, showing a selection of occluded attack actions in randomized order. After familiarization, the test started with a block of right-hander video stimuli followed by a left-hander block, interspersed by a short break of approximately 5 minutes. Within each block, the videos were presented in quasi-randomized order, starting at occlusion t_6 (fewest information) and ending at t_0 (full information) videos. The test duration was approximately 35 min.

Analysis

All data used in this study was recorded from the contact plates of the SpeedCourt® system. Dependent variables were response frequency (categorical) and decision time (in ms). A motor response was registered when leaving a contact plate and entering a new/the same contact plate. Decision time was defined as the time elapsed from the end of the video presentation to the beginning of the motor response (force on plate > 80 N).

An outlier detection procedure was applied based on decision time data, as proposed by Leys et al. (2013). Specifically, for starting, the absolute deviation around the time sample median for each occlusion point in each action was calculated. A moderately conservative rejection criterion of 2.5 times the median absolute deviation (MAD) below or above the median was defined. In other words, individual time data was categorized as outliers if their time value fell outside the predefined rejection criterion. If outliers of data points were detected, all related variables (i.e., choice of motor response, decision time) of the respective case were discarded from further statistical analysis.

Unless otherwise stated, the Statistical Package for the Social Sciences Version 26 (SPSS Inc., Chicago, IL, USA) was used for inferential statistics in the following analyses.

Statistical tests of significance carried out throughout the manuscript were performed two-sided, and the significance level was set to $p < .05$.

For the characterization of distinctions in decision-making behavior between elite and amateur players, the frequencies of the occurrence of each motor response (i.e., forward/tackling; passive/blocking; sideways right; sideways left) at each occlusion point were compared by the means of a chi-squared test. The magnitude of chi-square-based associations was evaluated using the effect size Phi (φ) (Kim, 2017). Phi was calculated by dividing the chi-square value by the sample size n and then taking the square root, yielding a value ranging from -1 to 1. The magnitude of φ can be interpreted using the following thresholds (Cohen, 1988; Kim, 2017): $0.1 < |\varphi| < 0.3$ "small", $0.3 < |\varphi| < 0.5$ "medium", and $|\varphi| > 0.5$ "large" effect. Note that negative values for φ denote higher frequencies in the elite player group and reverse for positive values.

To summarize evidence over the seven chi-squared tests (i.e., occlusion points t_6-t_0) belonging to each motor response and each action, partial two-sided *p*-values were combined into a single global *p*-value using Fisher's chi-square combination (Fisher, 1932):

$$\chi^2 = -2\sum_{i=1}^{k} \ln(p_i)$$

In case the combined null hypothesis of no between-group difference whatsoever is rejected, one can conclude that at least one of the partial null hypotheses is false. Put another way, Fisher's combination allows to combine multiple pieces of evidence to yield a style of meta-analytic result. Odds ratios (*OR*) with a 95% confidence interval (*CI*) were calculated (as described by Bland & Altman, 2000) by pooling all responses in each occlusion in the single attacks, in order to obtain summarized effect sizes of chi-square combinations. Note that Fisher's combination was only applied if the direction of between-group differences was consistent across all occlusion points. The above was done using the *poolr* package (Cinar & Viechtbauer, 2021) running in *R* v3.6.1 (R Core Team, 2013).

In a previous study (Hinz et al., 2021), as expected, quicker response times as a function of increasing amount of visual information were observed. However, it remains to be determined whether experts and amateurs differ with respect to decision times. To this end, the decision time data was subjected to a 2 (elite and amateur level) by 7 (occlusion time point $t_6 – t_0$) repeated measures analysis of variance (ANOVA). Before ANOVAs were calculated, all data was checked for normality using the Kolmogorov–Smirnov test.

Results

Decision-Making Behavior

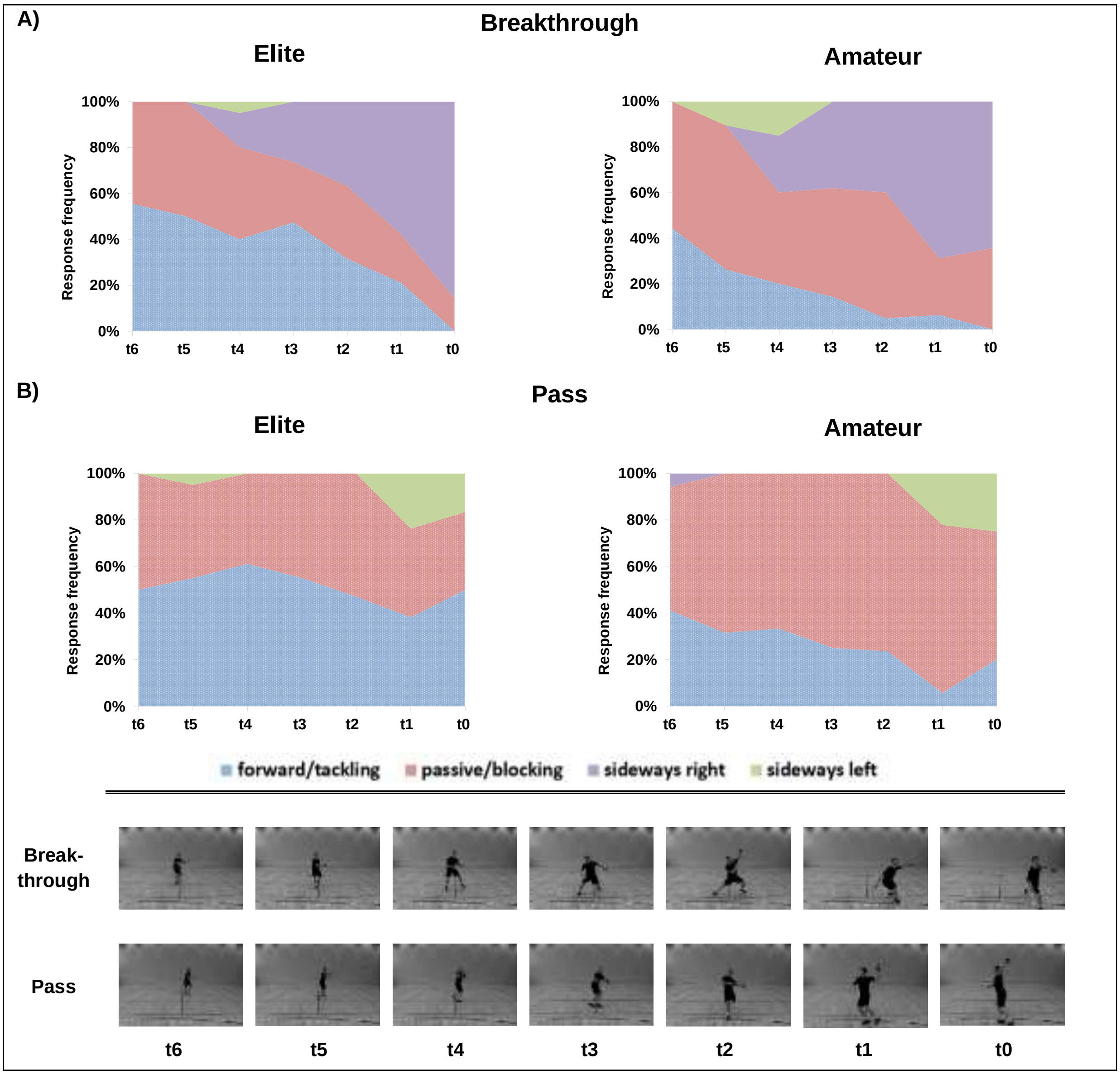

Figure 2.1. Illustration of significant different frequency distributions of motor responses in left-handed Breakthrough (A), and left-handed Pass (B) of elite (left) and amateur (right) players. *Note.* Stacked area graphs show occlusion points (*x*-axis) and (relative) response frequency (*y*-axis). Dotted areas denote significant frequency

distribution differences between groups. Screenshots of each video (and its constituent occlusions) are shown at the bottom.

Significant between-group differences of the response frequency distributions are shown in Figure 2.1. Significant effects of expertise were present in the left-handed Breakthrough and Pass only. Full illustrations of response frequency and distribution in all attacks, as well as individual chi-square statistics, are provided in the supplement material (Fig. E and F., Table A1 for right-handed and Table B1 for left-handed attacks).

Irrespective of group, visual inspection of frequency distributions shows dynamically changing response patterns over occlusion points, most likely due to the varying amount of visual information provided about the attacker's action. As indicated by significant results of Fisher's combination, the elite players responded significantly more often with forward/tackling movements in Breakthrough ($\chi^2(14) = 25.06$, $p = .033$, $OR = 2.76$, $CI = 1.54\text{-}4.95$) and Pass ($\chi^2(14) = 37.19$, $p = .001$, $OR = 3.00$, $CI = 1.78\text{-}5.04$). On the contrary, amateur players instead showed a more frequent use of passive/blocking in Pass ($\chi^2(14) = 28.28$, $p = .013$, $OR = 2.70$, $CI = 1.64\text{-}4.46$) (see Table B1 in Supplement). Of note, especially regarding single occlusion points with comparably few visual information, elite players use more frequently forward/tackling in Breakthrough (t_3: $\chi^2(1) = 5.20$, $p = .023$, $\varphi = -.36$). In Jump throw, elite players use more frequently forward/tackling in t_4 ($\chi 2(1) = 4.64$, $p = .031$, $\varphi = -.36$), but switching to more frequent passive/blocking responses at t_3 ($\chi 2(1) = 4.50$, $p = .034$, $\varphi = .35$). Another significant between-group difference was observed in Jump throw, where amateur players responded more often with a sideways right move (t_4: $\chi 2(1) = 3.90$, $p = .048$, $\varphi = .33$) (see Table B1 in Supplement).

Decision Time

Right-handed attacks		**Left-handed attacks**
	Breakthrough	
A)	**E)**	

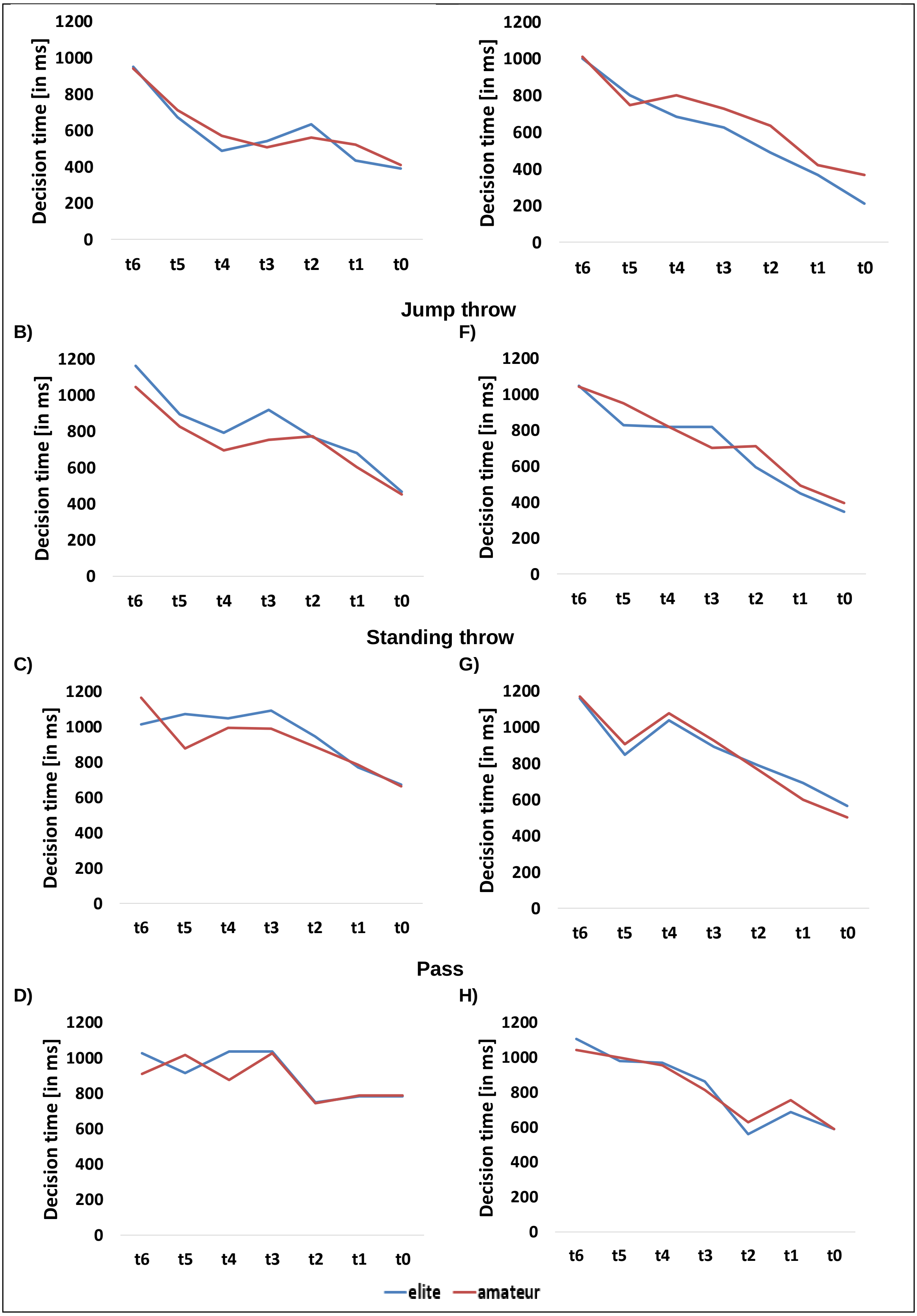

Figure 2.2. Comparisons of aggregated decision times for all responses between elite and amateur players in right- (A-D) and left-handed (E-H) attacks.

As expected, based on a previous study (Hinz et al., 2021), faster decision times occurred with increasing visual and kinematic information of the attacker in both groups (Fig. 2.2). This is evidenced by significant results for the main effect 'occlusion' in the repeated measures ANOVA in right-handed (Breakthrough: $F(6, 90) = 4.42$, $p < .001$; Jump throw: $F(6, 78) = 10.34$, $p < .001$; Standing throw: $F(6, 96) = 9.52$, $p < .001$; Pass: $F(6, 96) = 6.51$, $p < .001$) and left-handed (Breakthrough: $F(6, 84) = 27.48$, $p < .001$; Jump throw: $F(6, 96) = 32.51$, $p < .001$; Standing throw: $F(6, 120) = 18.67$, $p < .001$; Pass: $F(6, 114) = 17.29$, $p < .001$) actions. Between-group comparisons of the main effect 'expertise', however, revealed no significant effects. A significant group-by-occlusion ($F(6, 96) = 2.33$, $p < .038$) interaction was detected in the right-handed Standing throw. A detailed overview of ANOVA statistics is presented in Table C1 in the supplementary material.

Discussion

Considering the need of motor responses in expert decision-making research (Travassos et al., 2013), the current study compared the decision-making behavior between elite and amateur team-handball players, by using sport-specific motor responses in representative near-game test situations. To do so, the frequencies of selected responses were measured, which were given as a team-handball specific defense action on occluded video sequences showing varying attack actions. Additionally, the decision time each player required to initialize the respective response selected was evaluated too.

Regarding response frequency, significant effects of expertise in the left-handed Breakthrough and Pass were identified, where elite players demonstrated an overall significant preference to respond with forward/tackling movements on both attack actions. The amateur players, however, preferred to stay rather passive or blocking in Pass. More specifically, preferences for forward/tackling response or passive/blocking responses by the elite players in single occluded time points were also found (at t_4 in left-handed Breakthrough and left-handed Jump throw, and t_3 in left-handed Jump throw). Interestingly, the amateur players demonstrated significant more frequent sideways right responses in the left-handed Jump throw attack. Taken together, the differing frequencies of selected responses from both player groups suggest an expertise-dependent decision-making behavior. Expert effects in this study align with previous motor experiments in decision-making research in team-handball (Magnaguagno & Hossner, 2020; Raab, 2003), and extend them by new insights into how elite and amateur players differ in their tactical understanding of defending when limited visual information is provided.

Regarding decision time, a reciprocal decrease of the time was detected for the decision with increasing kinematic information in the presented attack actions (as found in Hinz et al., 2021). Despite the overall significance of this effect in all of the attacks, an expertise effect in decision time did not appear at all. To the best of knowledge, comparable decision (or response) time data from related motor experiments in team-handball using near-game environments do not exist (Bonnet et al., 2020). Previous non-motor experiments (Raab & Laborde, 2011) using offense sequences found expert players to decide better and faster, however, a similar study investigating the influence on mood on decision making found no expertise effect in decision time (Laborde & Raab, 2013). Likewise, the decision time data in this study was also not able to discriminate between groups. The comparability to both of the mentioned studies is to be seen with care, due to the specificity of the offense or defense situations the players were tested in, and due to the methodological aspect of sensorimotor responses in this test instead of verbal reports as responses.

Complex Sensorimotor Decisions Can Distinguish Expertise Levels

In order to classify the obtained findings regarding decision-making behavior, to the best of knowledge, the virtual reality study by Magnaguagno and Hossner (2020) is one of just a few comparable studies using a sport-specific motor approach to assess defense behavior in team-handball (Hinz et al., 2021; Magnaguagno & Hossner, 2020). Against the approach with four different attack actions in combination with multiple-choice responses, the patterns of play in their video sequences remained stable (lost or won 1 vs. 1 duel of teammate), and response choices were not prespecified. Similar to the expertise effects in decision making in this study, the authors detected significant expert advantages in the correctness of the given motor responses, but response times of the tactical decisions were not regarded, and differentiations of response outcomes regarding handedness of the attacker were also not undertaken. However, the comparability of results from both studies is partially restricted by the assisting role for the participants in the 2 vs. 2 group tactic situation in the Magnaguagno and Hossner study, in contrast to an active 1 vs. 1 situation. Nevertheless, the distinct anticipatory decision-making abilities between experts and near-experts in the mentioned study coincide with the obtained findings of stronger preferences for more offensive-orientated defense actions such as forward movement/tackling of the elite players. The expert players in the Magnaguagno and Hossner study equally demonstrated a significant more frequent tackling behavior.

An interpretation for the evident preferences of elite players for enhanced offensive movements (forward/tackling) in the left-handed attack actions (Fig. 2.1) could be that higher performing athletes use kinematic cues in anticipatory processes differently compared to their lower performing counterparts, as stated in research so far (Jackson et al., 2006; Johnston & Morrison, 2016). Put another way, based on the perception of kinematic cues throughout the attackers' movement, elite players could judge this visual information differently, resulting in an altered conversion into a motor response. Another explanatory approach could be found in the impact of the provided *context priors* to the players (Gredin et al., 2020) in combination with perceived kinematic cues of the attackers' actions. That elite players make different decisions than amateurs might be due to their expert knowledge and experience with the specified defensive tactics, the match status and/or the minute of play. The test instructions provided explanations about a man-to-man defense system players, and certain rules within this defense system apply, taught in basic practice lessons from early team-handball ages on (Pabst & Scherbaum, 2018). With increasing age and expertise level, elite players practice more often and compete higher, therefore learning and adapting defense systems on a higher competition level. It is therefore assumed that the elite players not only perceive the kinematic information of the attacking players' actions but also taking the increased risk for a wrong decision into account, which is enhanced by the tied game score and the approaching end of the match, subsequently making different tactical decisions than amateur players.

The present study also demonstrated assorted decision-making behavior in right- and left-handed attacks, which transfers the hand-specificity effects from recent *embodied-choice* experiments (van Maarseveen, Savelsbergh et al., 2018) into the current test setting. Previous research on hand-effects in team-handball found evidence for the lack of familiarity with less frequent left-handed opponents (Baker et al., 2013; Loffing, Sölter et al., 2015), and the dependence on an observers' domain-specific skill to identify the opponent's unfolding action (Loffing, Sölter et al., 2015). The results obtained from the present study suggest that laterality effects on handball-specific decision making can also be observed in test settings involving motor responses.

Elite Players Invest More Time For Different Decisions

Expectedly, the decision times generally decreased with an increasing amount of visual information as detected in previous team-handball experiments (Cocić et al., 2021; Laborde & Raab, 2013; Loffing, Sölter et al., 2015; Raab & Johnson, 2007; Raab & Laborde, 2011). Unexpectedly, the nonexistent differences in decision time between elite and amateur players are in contrast to previous team-handball studies that determined experts to make better and faster decisions (Raab & Laborde, 2011). It may be assumed that this discrepancy is at least in part related to differences in the experimental setups between studies (e.g. response methods, sample sizes, sub-sample expertise). Providing responses verbally (or via keystroke) might yield different outcomes as compared to motor responses in a performer environment setting, as presented in the literature (Huesmann et al., 2021; Ranganathan & Carlton, 2007). At this point, it can only be speculated about the reason for this apparent discrepancy.

Considering motor response times in multiple-choice tasks (Ratcliff et al., 2016) suggests an increase in insights in cognitive-motor differences between domain-specific expert levels. In their meta-analysis, Travassos et al. (2013) found a moderating effect of requisite responses on decision time in decision-making experiments ($p < .001$). A closer inspection on expertise difference for decision time under in situ conditions in their analyses revealed non-significant differences between performance level (p = .82), provided solely by two appropriate studies in the review. Despite the small number of studies, these findings are in agreement with the non-discriminating effect of decision time in the revealed results.

With reference to the complexity of the decision-making setup, and the expertise-related decision-making behavior, it is assumed that *dynamic inconsistency* mechanisms affect the characteristics of individual decisions in the test sample. *Dynamic inconsistency* (Raab, 2003; Raab & Johnson, 2007) explains the tendency to deliberately select a better response option after a first intuitive option that came to an athletes' mind. In this regard, equal decision times might be a consequence of expertise-related top–down (cognitive control of sensory processing) and bottom–up (absence of cognitive control in sensory processing) processes (Raab, 2014) in experts compared to amateurs. This deliberate (also considered as corrective) decision-making behavior can be conjectured to be the decisive one that may impact the required time to choose the final decision, and subsequently the decision outcome itself. It can thus be conceivably hypothesized that the perceived kinematic information of the attackers' unfolding action lead to a first intuitive decision preference in both the elite and amateur players (Raab & Laborde, 2011), preparing a motor response tendency towards the attacker (Raab, 2014). But with further kinematic cues in the ongoing time-motion course (occlusions) of the attackers' action, the additional perceived information seem to be judged differently by the elite players compared to the amateur players. The elite players may use recent kinematic information (bottom-up process) for a short-term switch to a more appropriate response, evoked by additional time investments. Such a tendency to switch may depend on accumulated, competitive experiences that equip experts with domain-specific knowledge about situation-specific optimal choices (Raab, 2014, 2020). The suspected corrective and deliberate decisions in elite players in the present study differ to some extent from the faster, intuitive decisions of experts in the reported literature (Laborde & Raab, 2013; Raab & Johnson, 2007; Raab & Laborde, 2011;). Nevertheless, the comparison of the findings within this context has to be done with care due to the decoupled perception-action responses used in these studies, and the coupled perception-action responses in this study, which could possibly lead to divergent performance outcomes (Farrow et al., 2005; Huesmann et al., 2021; Ranganathan & Carlton, 2007).

Overall, the sport-specific motor approach detected distinctions in decision making between players of varying performance levels. Hence, future analyses of sensorimotor decision making with *take-the-first* (Johnson & Raab, 2003) and *take-the-best* (Gigerenzer et al., 1999) heuristic models seem promising.

Limitations and Future Research

It must be emphasized that derivations to real-world behavior needs further methodological adjustments in the experimental design.

It still remains open, if the findings obtained in this study reflects the actual on-field behavior of the players. Comparisons of the lab-based performance to the players' on-field performances during a team-handball match would have allowed for further correlations with the data in the study. The players' on-field performances in play could have been captured by using a notational system (expert ratings of players' actions with scores) applied by van Maarseveen, Oudejans et al. (2018) in soccer. However, a validated team-handball-specific notational system is not existing so far.

Furthermore, players' physical appearance (height, weight), physical skills (speed, agility), and technical skills (high or low level skills, position-specific skills) are performance-discriminating contextual features in team-handball (Wagner et al., 2014), but, for methodological reasons, these features were standardized in the present study. For example, the physical appearance of a backcourt player also affects defense behavior of a central block player, meaning that a taller backcourt player prefers to make advantage of his height by using long distance throws from the backcourt, whereat smaller players rather prefer breakthrough actions in near-range distance towards the 6 m line. Consequently, there are common tactical approaches to defend taller backcourt players by early tackling them to avoid long rage throws.

For this reason, a standardized test protocol was chosen that minimized such contextual features.

Also, intra-individual differences within the expert group itself (elite players) can also affect the obtained performance outcomes, as revealed by the TO study of expert field hockey goalkeepers (Morris-Binelli et al., 2021).

Further experimental investigations are needed to address the influence of *context priors* (Gredin et al., 2020) on decision making in representative task designs. Specifically, future studies could integrate *stable priors* either verbally with coach-like instructions (typical in a match preparation) about action preferences of a special opponent in the stimuli (see Helm et al., 2020; Lüders et al., 2020) or the tactical direction (see Levi & Jackson, 2018). *Dynamic priors* in terms of a visual response-depending match status (Farrow & Reid, 2012) as feedback would reinforce the pressure condition during the match. Eye-trackers could gain insights about the utilization of kinematic information in the video stimuli in the test (Brams et al., 2019; Dicks et al., 2010).

Due to the qualitative (response frequency) and quantitative (decision time) variables used in this study, T-pattern analyses, a software-based mixed methods approach, could give additional enlightenment about the temporal structure of the player's decision behavior (Magnusson, 2000). T-patterns are dendrograms, showing the order and the temporal distributions of occurrences, as well as recurring series of behavioral occurrences. In other words: 'if A is an earlier and B a later component of the same recurring T-pattern, then, after an occurrence of A at t, there is an interval that tends to contain at least one occurrence of B more often than would be expected by chance (Magnusson, 2000). Pic (2018) found more T-patterns in home teams compared to away teams in team- handball, meaning that home teams showed repeating patterns of throws in the left and right areas towards the opponent goalkeeper with greater chances for success. Future analyses with this method could explain strategic details and the temporal distributions in defensive decision-making processes, such as repeating slower but better defense responses on specific attack actions.

Conclusion

In summary, the findings in this chapter attest overall test sensitivity of the created representative, sensorimotor test due to the accumulating evidence of expertise-related decision-making behavior, and also facilitating test validity at the same time. In detail, the observed expertise effect in response frequency indicates preferences for forward/tackling responses of elite players. The results are also indicative of *dynamic inconsistency* mechanisms from *simple heuristics* literature (Raab, 2003; Raab & Johnson, 2007; Raab & Laborde, 2011). Thus, a nonexistent expertise effect in decision time may suggest that the required time for making a decision could play a more important role in decision making and *simple heuristics* than previously assumed. Taken together, the findings serve recent calls in sport science for an enhanced utilization of multidisciplinary test approaches when assessing complex sportive behavior of athletes. Talent detection and identification processes should henceforth apply sport-specific performance tests which take the perceptual-cognitive capabilities of athletes into account. Considering decision making in performance analyses could provide a more holistic estimate of an athletes' talent and performance potential, as a product of the athletes' sensory and biomotor capacities at the same time.

Chapter 4

Elite Players Invest Additional Time For Making Better Embodied Choices

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Abstract

Expert effects in decision-making research is declared as most apparent when actually performing sport-specific motor responses. However, experiments requiring motor responses, being considered as *embodied-choice* paradigms, are still underrepresented. Furthermore, it is less understood, how decision time and confidence depend on the type of embodied choices players make. To scrutinize decision-making processes (i.e., decision time, decision confidence), the aim of this chapter is to investigate the embodied choices of male athletes with different expertise in a close-to-real-life environment. 22 elite (M_{age} = 17.59 yrs., *SD* = 3.67) and 22 amateur (M_{age} = 20.71 yrs., *SD* = 8.54) team-handball players performed an in situ *embodied-choice* test. Attack sequences (*n* = 32) were shown to the players, who had to make a choice between four provided options by giving a respective in situ motor response. The frequencies of *specific choice* and the *best choice* were analyzed, as well as the respective decision time and decision confidence. Elite and amateur players differed in the frequencies of *specific* choices (i.e. forward/tackling; passive blocking), and elite players made the *best choice* more often. Slower decision times of elite players were revealed in *specific choices* and in *best choices*, confidence of decisions was rated equally high from both player groups. Indications are provided that elite players make better choices rather slower, instead of faster. Assumably, this could be due to specific sensorimotor interactions and speed-accuracy-tradeoffs in favor for accuracy in elite players. The findings extend expert decision-making research by using an *embodied-choice* paradigm, highlighting considerations of decision time and confidence in future experiments.

Keywords: *decision making, decision time, decision confidence, team-handball, expertise*

Introduction

Extensive research in cognitive psychology in sports attribute superiority in decision making to expert athletes (Araújo et al., 2017; Mann et al., 2007; Silva et al., 2020; Travassos et al., 2013). However, most research conducted experiments without the consideration of motor executions or by simply capturing highly restricted micro-movements (e.g., button press, pointing, verbal reports) (Araújo et al., 2017). These methodological issues challenge the ecological validity of the experimental representation, and the theoretical as well as practical implications of findings (Araújo et al., 2007; Mann et al., 2010; Travassos et al., 2013). Trying to address these shortcomings, recent developments in decision-making research aim to carry out experiments with a coupling of perception, cognition, and action, based on an embodied cognition perspective (Araújo et al., 2017; Raab & Araújo, 2019). The experimental designs therein involve representative task constraints and sport-specific motor responses under in situ conditions (Bruce et al., 2012; van Maarseveen, Oudejans et al., 2018, van Maarseveen, Savelsbergh et al., 2018). In situ conditions means that researchers use real-world game contexts in order to capture close-to on-field decision making (Ericsson & Ward, 2007), e.g. capturing goalkeeper-specific movements in response to penalty kicks presented in videos (Dicks et al., 2010). In situ tests using motor responses are stated to enhance empirical validity in decision making research (Travassos et al., 2013), because they a) provoke the greatest behavioral differences between athletes of different expertise levels (Dicks et al., 2010; Dicks et al., 2019; Morris-Binelli & Müller, 2017; Roca et al., 2011; Travassos et al., 2013), and b) provide further insights into decision-making processes under time constraint by considering decision times (Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007; van Maarseveen, Savelsbergh et al., 2018).

A decision-making theory that has been used to explain sports decisions (Raab, 2012), and has been tested with sport choices (e.g., Belling et al., 2015; Hepler & Feltz, 2012; Musculus, 2018; Raab & Johnson, 2007) is the so-called theory of *simple heuristics* (Raab, 2012), also emphasizing the need of considering in situ motor execution as a central building block of sports decisions. *Simple heuristics* have recently been expanded from an embodied cognition perspective in order to account for the interaction of cognitive and motor processes throughout the decision-making process and for motor execution of choices in particular (Raab, 2017a). Therefore, the integrative concept of *embodied choices* (Lepora & Pezzulo, 2015) is the theoretical starting point of the present study.

Embodied Choices in Sports

In particular, *embodied choices* are rules of thumbs that appear when athletes have to decide quickly between several options while under time constraints (Raab, 2017a). Decision-making studies in sports that can be interpreted from an *embodied-choice* perspective are studies which already captured sport-specific motor responses.

To the best of knowledge, only one study within the *embodied-choice* framework exists that examined *embodied choices* in an in situ paradigm with regard to choice quality. Van Maarseveen, Savelsbergh et al. (2018) used a 3 vs. 3 pick-and-roll basketball play with three types of defensive play, and participants assumed the role of the ball carrier. Analyses of the tactical decisions made, and the quality of decisions (determined by two coaches as correct or incorrect decisions), showed that players made different decisions on either the left or right side of the court, and when they faced different defensive plays. The quality of choices did not differ between the defensive plays and side of the court, and expertise comparisons were not conducted in this study.

Another embodied examination in team-handball compared expert and near-expert players' decision-making performances in an in situ cave automatic virtual environment (Magnaguagno & Hossner, 2020). Attack sequences were presented showing 1 vs. 1 situations of a defending teammate and a backcourt attacker, and players were required to give an embodied defense response. The authors found expertise effects in response correctness, showing that expert players responded more appropriately on a lost 1 vs. 1 duel of the respective defending teammate than the near-expert players.

Nevertheless, given the low numbers of studies so far, *embodied-choice* paradigms are needed in order to not only facilitate the understanding of real-world behavior of athletes, but also to validly investigate the mechanisms underlying *embodied choices*. *Embodied-choice* paradigms allow the assessment of not only the accuracy of decisions but also the time of the decisions made, being determined to discriminate between expertise levels (Travassos et al., 2013). Additionally, the confidence of the decisions is another fundamental aspect in decision making, especially for multiple-choice alternatives (Ratcliff & Starns, 2013).

Time and Confidence in Sports Decision-Making

In cognitive science, decision-making theories often model response times because they are regarded as a crucial measure of performance (Ratcliff et al., 2016). For example, a decision can be made faster with sacrificing accuracy, a decision can also be more accurate with sacrificed decision speed (speed-accuracy tradeoff) (Ratcliff et al., 2016). In order to be able to further estimate the speed and accuracy, it is also very common to assess the confidence of the judgment of a decision (Ratcliff et al., 2016; Seale-Carlisle et al., 2019).

For decision making in sports, which is characterized by the highly dynamic, frequently changing, and time-pressured situations (e.g. Belling et al., 2015; Musculus, 2018; Musculus, Raab et al., 2018; Raab, 2012), decision time and confidence are crucial indicators about *how* decisions are made as they are. In detail, these situations challenge athletes to make fast decisions and to confidently rely on their judgment even if alternative options evolve quickly through the dynamic changes.

Regarding decision time, the *embodied-choice* study of van Maarseveen, Savelsbergh et al. (2018) in basketball also measured the decision time (duration from catching the ball of an initial pass until releasing the ball for pass, lay-up or shot) of the correct and incorrect decisions within their in situ 3 vs. 3 pick-and-roll plays. The average execution time of correct decisions was 2652 ms, and 2951 ms for incorrect decisions, with almost obtained significance (p = .092, r = .49). In soccer, the studies of Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts (2007) and Vaeyens, Lenoir, Williams, & Philippaerts (2007) used pressure-sensitive sensors to assess decision times within their experiments. With the execution of movement-based responses on varying offensive patterns of play presented on a life-sized projection screen, the authors detected faster decision times in successful players. In non-motor heuristic studies in team-handball, decision time was found to be a performance-discriminating factor between experts, near-experts and non-experts (Raab & Laborde, 2011), showing experts' faster and better tactical decision making based on their intuition. As decision time seems to play an important role in decision-making processes, the interactions of decision-making performance and decision time in an *embodied-choice* context is still less examined.

Only a few studies in the team-sports domain exist which measured the athletes' confidence in decisions. In a basketball study by Hepler and Feltz (2012), they applied a video-based cognitive decision making test, results for decision confidence (defined as the subjective estimation of the success of a decision made) indicate that basketball players were more confident in better options and choices. A study with young expert players in soccer found correlations between decision confidence and motor confidence (both as Likert-type scale), which was defined as the subjective estimation of the ability to execute a respective option (Musculus, Raab et al., 2018).

Again, the studies presented did not consider sport-specific motor responses and, therefore, there is less knowledge about how decision confidence relates to *embodied choices* in sports. To the best of knowledge, only one sport study assessed decision confidence in an *embodied-choice* setting testing with sport-specific motor responses (Hinz et al., 2021). Thus, further embodied research is needed to better understand how decision time and confidence are affected, not only by the choices made and its quality, but also by differing levels of expertise.

Together, decision time and confidence in specific choices are relevant parameters that have been strongly recommended by cognitive scientists to be taken into account in decision making experiments (Ratcliff et al., 2016; Ratcliff & Starns, 2013). This might hold for sports in particular, given the time constraints and uncertainty through dynamic changes. Despite the highlighted advantages of embodied cognition paradigms, studies, which investigate the decision time and confidence with respect to *embodied choices*, are lacking. Thus, the type of the *embodied choices* the elite and amateur team-handball players made was examined, and how decision time and decision confidence is affected by the respective choices of players.

The Present Study

To summarize, this paper extends current theorizing and the empirical state-of-the-art by testing *embodied choices* in an in situ paradigm in team-handball, which allows to analyze 1) what choices are made through capturing a sport-specific motor response, and 2) how decision time and confidence differ based on these choices made.

In particular, the expertise effects in decision making were investigated with an in situ *embodied-choice* paradigm. It was looked at 1) what choices elite players make and 2) how often those choices are the *best choices* (cf., decision rule of the TTB heuristic). By analyzing expertise effects, it was also looked at the interaction between expertise and the type of choices. By doing so, it was possible to further scrutinize the decision-making processes (i.e., decision time, decision confidence), underlying the elite and amateur players' choices. In detail, decision time and decision confidence were analyzed, because these are theoretically linked and practically crucial for sport choices. To do so, in a first step it was analyzed which choices elite players made in comparison to amateur players [1a], to then examining how long players of different expertise took to make *specific choices* and how confident they were about those [2a]. In a second step, it was looked at the *best choices* in particular. In detail, it was analyzed how often elite players and amateur players made the *best choice* [1b], as well as how long it took players of different expertise to do so and how confident they were regarding these choices [2b]. Figure 3.1 provides a brief overview about the created test design.

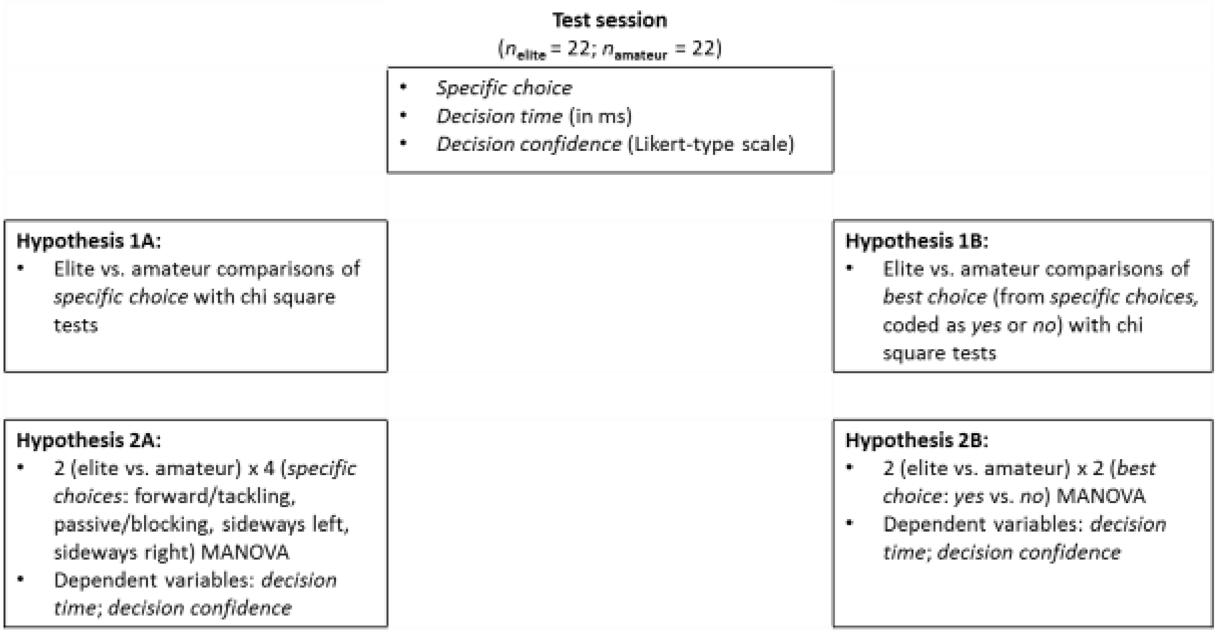


Figure 3.1. Illustration of the study design including the respective hypotheses.

In detail, it was assumed that the elite players would make different *embodied choices* than amateur players (Magnaguagno & Hossner, 2020; van Maarseveen, Savelsbergh et al., 2018) which should be reflected in the frequencies of the *specific choices* [1a]. For *decision time* and *decision confidence*, it was expected that, based on their expertise, the elite players would make their *embodied choices* faster (Raab & Laborde, 2011; Travassos et al., 2013) and with higher confidence (Hepler & Feltz, 2012) [2a].

Further, higher frequencies of the *best choice* for elite players [1b] were predicted, based on the team-handball study of Magnaguagno and Hossner (2020). According to *simple heuristics* in sports (Raab, 2012), it could be assumed that the *best choices* of the elite players are made faster and elite players are more confident in their selections of the *best choices* than amateurs [2b]. However, there is no empirical evidence so far, that compared decision confidence between expertise levels.

Materials and Methods

Participants

The participants in this study were part of a previous decision-making experiment (Hinz et al., 2021) in which attack sequences were presented with the TO paradigm (Jones & Miles, 1978) instead, and with differing test instructions.

Based on the within-between interaction effects of two previous studies assessing decision making in realistic setups (Bruce et al., 2012; Raab & Johnson, 2007), an a priori power analysis was conducted for planned multivariate analyses of variances (MANOVA) with global factors (with 1 – beta error probability =.95; alpha error probability = .05; number of groups = 2; response variables = 4; effect size f = 0.48 for being the lowest in Raab, 2011) using G*Power 3.1.9.7 (Faul et al., 2007), revealing a minimal total sample size of 32 participants. Therefore, the total sample size of 44, and the sub-sample sizes of 22 in each group seemed sufficient.

The total sample consisted of 44 male team-handball players (M_{age} = 19.11 yrs.; SD = 6.56 yrs.), who came from four different teams from different performance levels. Twenty-two players (M_{age} = 17.59 yrs., SD = 3.67) were part of a professional youth academy of a First League team-handball club, competing in the highest possible league within their age category. Based on the definition by Swann et al. (2015), these players can be considered as elite team-handball players. Twenty-two players (M_{age} = 20.71 yrs., SD = 8.54) were part of local team-handball clubs, competing in nonprofessional, regional leagues. These players are considered as amateur players (Room, 2010). Differences in age between both groups were not significant (p = .952).

The study received approval by the ethics committee from the local university, and met all requirements of the Declaration of Helsinki and its later amendments.

Apparatus and Stimuli

The experimental setup of the decision making test was adopted from earlier examinations (Hinz et al., 2021) and applied in an in situ paradigm. The test scenario, which was presented on a life-size projection screen in front of a contact plate system (SpeedCourt

Q12 PRO mobile, GlobalSpeed, Hemsbach, Germany), consisted of attack sequences, showing a centre back player from the view of a central defender. The scenario included video trials with four representative attack actions, and four dummy trial videos (both right-handed attacker) showing too ambiguous actions for an appropriate defence response (for the avoidance of expectation effects; Anderson, 1983). The video clips were all doubled, mirrored (to create a left-hander version of each video trial), and presented in a quasi-randomized order within two blocks, beginning with a right-hander attack block, followed by the left-hander video block, with a two-minute break in-between.

The specific response choices (*forward/tackling; sideways left, sideways right; blocking/passive*) that were prespecified to the contact plates of the SpeedCourt® system, were adapted from the previous decision making test (Hinz et al., 2021). Please refer to this paper for detailed explanations regarding response choice mapping and test environment.

The videos were sized 1280 x 720 pixels (width x height). The test scenario was implemented by using the *Lazarus* (Version 2.0.10) software. In total, the final test scenario consisted of thirty-two video clips of attack sequences of two seconds each, which were presented to the participants during the measurement procedures.

The decision-making test was checked for cross-sectional and longitudinal reliability dimensions (Hinz et al., 2021), which revealed moderate level of reproducibility. In further statistical analyses only the first presented videos of the attacks (4 right-hander and 4 left-hander attacks) was used, in order to obtain unbiased responses behavior without memory effects in the participants.

In order to assess the quality of decisions, four international team-handball experts for a rating of the best tactical choice to finally determine the *best choice* variable were recruited. The four expert raters were characterized by at least 10 years of continuous championship seasons in the German First League, by competing for their adult national teams, and by achievements of national and international club level titles (European Handball League, European Handball Champions League, European Club Championship, German

Championship) as former players and coaches. Prior to the main experiments, rating sessions took place in the final test setup all participants were tested with later as well. In individual sessions, all four right-hander attack sequences were presented to the experts on the projection screen, and experts required to execute an in situ motor response on the attacks, with one of the four prespecified defence responses. Then, experts were asked to evaluate the given options for each scene, based on a six-point Likert-type scale (1 = absolutely ambiguous, 2 = ambiguous, 3 = indecisive, 4 = tendentious, 5 = unambiguous, 6 = absolutely unambiguous). In detail, they were asked on the judgement of the best tactical choice, and competition-similarity of the shown attacks.

To determine the *best choice*, a 'majority rule' procedure according to Johnson and Raab (2003) was applied: For each of the eight video trials, when 3 out of 4 experts evaluated the same option as being the best tactical choice, this decision was coded as the *best choice*. Given the four baseline stimuli, namely the 4 right-hander attack actions, the experts agreed on the best decision in 75 % of the cases. This majority rule is also statistically supported by a chi-squared test with Monte Carlo simulation (2000 replicates), where it was found that an observed agreement of three out of four raters differs significantly from chance probability (i.e., 1/4, $\chi^2 = 5.33$, $p = .049$). The raters' selection demonstrated also satisfying judgements for the perceived competition-similarity ($M = 5.6$; $SD = 0.6$). The *best choice* was coded in the data base with *best choice* selected (1 = *yes*) or not (0 = *no*).

Procedure

Before start of the single test sessions, written informed consent of parents of the underage participants was obtained. After an autonomous, game-specific warm-up (about 5 min), explanations about the experimental setting and test procedure were provided by the test staff. Starting with standardized oral instructions, the players were instructed to put themselves in the position of the central block defender in a classic man-to-man defence without teammates, or other opponents than the attacker in the video/situation. Then, four familiarization videos were provided to get used to the test environment. In the main test session, the participants were challenged to execute a defence-specific motor response in situ to the attack sequences in the video clips, as if they would defend the attacker in a real game situation. Following their first intuition, they were allowed to initialize their motor response whenever required. When a participant left the starting contact plate (central plate), the projection screen turned black for the avoidance of a response bias. After each motor response, participants were asked about their self-perceived decision confidence about the appropriateness of their made response choice, with a Six-point Likert-type scale (1 = absolutely ambiguous, 2 = ambiguous, 3 = indecisive, 4 = tendentious, 5 = unambiguous, 6 = absolutely unambiguous). One test session took about 15 min in total.

Statistical Analysis

Dependent variables (DVs) were decision time (interval-scaled, in ms), measured as the elapsed time from start of a video trial till leaving the starting contact plate, and decision confidence (interval-scaled, Likert-type scale). In preparation for the analysis, all data points from the eight video trials of the decision-making test were excerpted. Based on the total sample size of N = 44, 352 data points for each variable were received. Preceding outlier detections were conducted by calculating the median absolute deviation (MAD) around the sample median of decision time (separately for each action) according to the recommendations by Leys et al. (2013). A moderately conservative rejection criterion of 2.5 times the MAD below or above the median (Leys et al., 2013) were defined, in order to identify individual time data as outliers. If a case exceeded the rejection criterion value, all associated variables (i.e., decision time, decision confidence, *specific* and *best choice*) were discarded from further statistical analyses.

In a first step, the *embodied choices* made by elite vs. amateur players were compared with chi-squared tests. Specifically, it was looked at the frequencies of the *specific choices* made [1a], and at the frequencies of making the *best choice* [1b]. To aid the interpretation of chi-squared test results, the effect size Cramer's V (Kim, 2017) was calculated. To this end, the chi-square value was divided by the sample size n and then the square root was taken, yielding a value ranging from -1 to 1. The general difference in the frequencies of all four *specific choices* and *best choice* (*yes* vs. *no*) between elite and amateur players was tested, as well as single between-group differences in each of the *specific choices*. Cramer's *V* values for the four *specific choices* (df = 3) can be interpreted as laid down by Kim (2017): 0.06 < $|\varphi|$ < 0.17 "small", 0.17 < $|\varphi|$ < 0.29 "medium", and $|\varphi|$ > 0.29 "large" effect. Cramer's *V* values for *best choice* (*yes* vs. *no*; df =1) can be interpreted with: 0.06 < $|\varphi|$ < 0.17 "small", 0.17 < $|\varphi|$ < 0.29 "medium", and $|\varphi|$ > 0.29 "large" effect (Kim, 2017).

In a second step, it was looked at the interaction effects of the different expertise groups and their *specific choices* made [2a], as well as at the interaction effects of the different expertise groups and their *best choices* made [2b] with the decision-making process variables decision time and decision confidence. This was analyzed with two separate mixed MANOVAs, i.e., a 2 (expertise $group_{between}$: elite vs. amateur) x 4 (specific $choice_{within}$: forward/tackling; passive/blocking; sideways left; sideways right) and a 2 (expertise $group_{between}$: elite vs. amateur) x 2 (best $choice_{within}$: yes vs. no) with the dependent variables decision time and decision confidence. If significant multivariate main and interaction effects were obtained, those were followed up with subsequent univariate analyses to check which of the obtained dependent variables were affected. Assumption checks revealed that the Box's M-test for homogeneity of covariances was not significant for the *specific choice* MANOVA, but significant in the *best choice* MANOVA (p = .009). Shapiro-Wilk tests for multivariate normality were violated (both *p*s < .001), however, both MANOVAs were conducted in accordance to the guidelines of Finch (2016). Cohen's d was calculated as a measure of effect size, with interpretations against the following scale: 0.2 > d, trivial; 0.2 ≤ d < 0.5, small; 0.5 ≤ d < 0.8, moderate; 0.8 < d , large (Cohen, 1988). The significance level was set at α = .05. Data analyses were conducted using Statistical Package for the Social Sciences Version 26 (SPSS Inc., Chicago, IL, USA).

Results

Specific Choices

Table 2.1

Descriptive statistics of specific choice and the respective decision time and decision confidence in both player groups.

Group	Specific choice	Frequency (*n; %*)	Decision time (*M* ± *SD* in ms)	Decision confidence (*M* ± *SD on Likert-type scale*)
Elite				
	forward/tackling	72 (44.7 %)	1920 ± 298	4.7 ± 2.0
	passive/blocking	69 (42.9 %)	2058 ± 305	4.3 ± 1.2
	sideways right	11 (6.8 %)	1909 ± 393	4.9 ± 1.2
	sideways left	9 (5.6 %)	2049 ± 349	5.2 ± 0.8
Amateur				
	forward/tackling	32 (20.6 %)	1704 ± 459	4.6 ± 0.8
	passive/blocking	96 (62.6 %)	2084 ± 332	4.8 ± 1.0
	sideways right	11 (7.1 %)	2092 ± 340	4.8 ± 1.2
	sideways left	15 (9.7 %)	2211 ± 387	4.3 ± 1.1
Both				
	forward/tackling	104 (33.3 %)	1853 ± 370	4.6 ± 1.1
	passive/blocking	165 (6.7 %)	2073 ± 356	4.6 ± 1.1
	sideways right	22 (52.4 %)	2000 ± 387	4.9 ± 1.1
	sideways left	24 (7.6 %)	2150 ± 389	4.7 ± 1.3

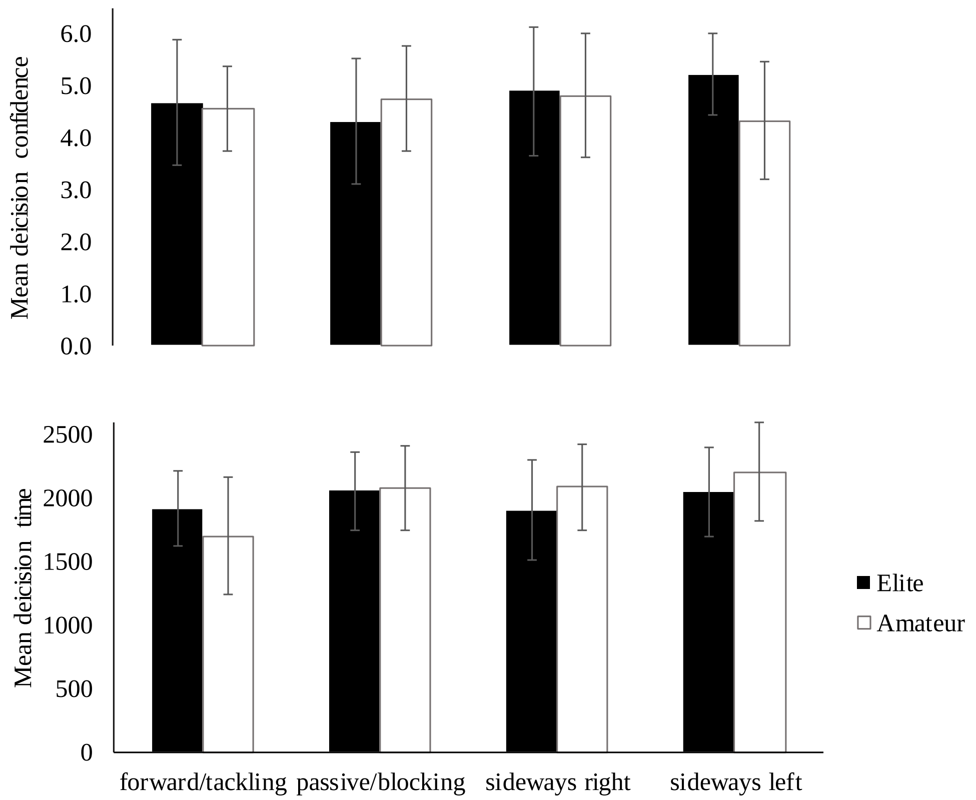


Figure 3.2. Decision time (in ms) and decision confidence (on Likert-type scale) of specific choices of elite and amateur players. Error bars indicate standard deviation.

Descriptive statistics of the *specific choices* and related decision times and decision confidences are presented in Table 2.1 and Figure 3.2.

Descriptive statistical analyses showed that elite players used forward/tackling most frequently (44.7 %), and sideways left least frequently (5.6 %). Amateur players used passive/blocking most frequently (62.9 %) and sideways right least frequently (7.1 %).

Testing for expertise effects in *specific choice* (Hypothesis 1a), significant chi-squared test results showed that elite and amateur players indeed differed in how often they made *specific choices*, $\chi^2(3) = 21.501$, $p < .001$, Cramer's $V = 0.26$. In particular, single between-group differences in forward/tackling ($\chi^2(1) = 8.94$, $p = .004$) and passive/blocking ($\chi^2(1) = 21.84$, $p < .001$) were also revealed, while other choice frequencies (i.e., sideways right and left, *p*s > .05) did not differ significantly between expertise groups.

The MANOVA analysis of whether the decision-making processes of elite and amateur players differed based on their *specific choices* made (i.e., expertise × specific choice interaction; Hypothesis 2a) did not show a main effect of *expertise* (Wilks's $\lambda = 1.00$, $F(1, 308) = 0.46$, $p = .663$) but revealed a significant main effects of *specific choice* (Wilks's $\lambda = .91$, $F(1, 308) = 4.89$, $p < .001$) and a significant *expertise* × *specific choice* interaction (Wilks's $\lambda = .94$, $F(3, 308) = 3.24$, $p = .004$).

Following up the significant multivariate main effect for *specific choice* and the *expertise* × *specific choice* interaction, subsequent univariate analyses for *decision time* showed that *specific choice* $F(3, 308) = 8.79$, $p < .001$, $\eta_p^2 = .106$) and the *expertise* × *specific choice* interaction $F(1, 308) = 3.25$, $p = .022$, $\eta_p^2 = .036$) were significant. In detail, scrutinizing the main effect of *specific choice* revealed that the forward/tackling choice was significantly faster than the passive/blocking choice ($t(267) = -5.140$, $p < .001$, $d = 0.65$) and the sideways left choice ($t(126) = -3.504$, $p < .001$, $d = 0.80$). All other *specific choice* comparisons were not significant. Following up the significant *expertise x specific choice* interaction revealed only that elite players were significantly slower than amateur players in their forward/tackling choice ($t(102) = -2.840$, $p = .005$, $d = -0.60$) while there were no other significant effects of expertise.

Univariate analyses for *decision confidence* revealed only a significant *expertise* x *specific choice* interaction *F*(1, 308) = 3.08, *p* = .028). Elite players were less confident in their passive/blocking choice than amateur players (*t*(163) = 2.536, *p* = .012, *d* = 0.40). No significance was revealed in the all other *specific choice* comparisons (Tab 2.1., Fig. 3.2.).

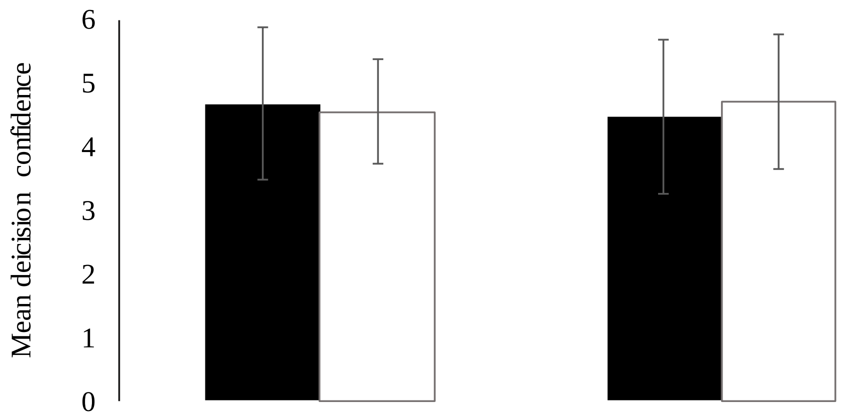
Best Choice (i.e., decision rule of the *take-the-best* heuristics)

For the analyses of the *best choice* (i.e., TTB prediction) in the in situ *embodied-choice* paradigm, the frequency of the best options chosen in both expertise groups (Hypothesis 1b) were checked. The respective chi-squared tests revealed that indeed elite players (44.7 %, *n* = 72) made the *best choice* more often than amateur players (20.8 %, *n* = 32), $\chi^2(1) = 20.400$, *p* < .001, Cramer's V = 0.25.

Table 2.2.

Descriptive statistics of selected (yes) and non-selected (no) best choice in amateur and elite players.

Group	Best choice frequency (*n*, %)		Decision time (*M* ± *SD* in ms)		Decision confidence (*M* ± *SD* of Likert-type scale)	
	yes	**no**	**yes**	**no**	**yes**	**no**
Elite	72 (44.7 %)	89 (56.3 %)	1920 ± 298	2039 ± 325	4.7 ± 1.2	4.5 ± 1.2
Amateur	32 (20.8 %)	121 (79.2 %)	1704 ± 459	2099 ± 315	4.6 ± 0.8	4.8 ± 1.0
Both	104 (33.1 %)	210 (66.9 %)	1979 ± 369	2074 ± 337	4.7 ± 1.1	4.6 ± 1.1



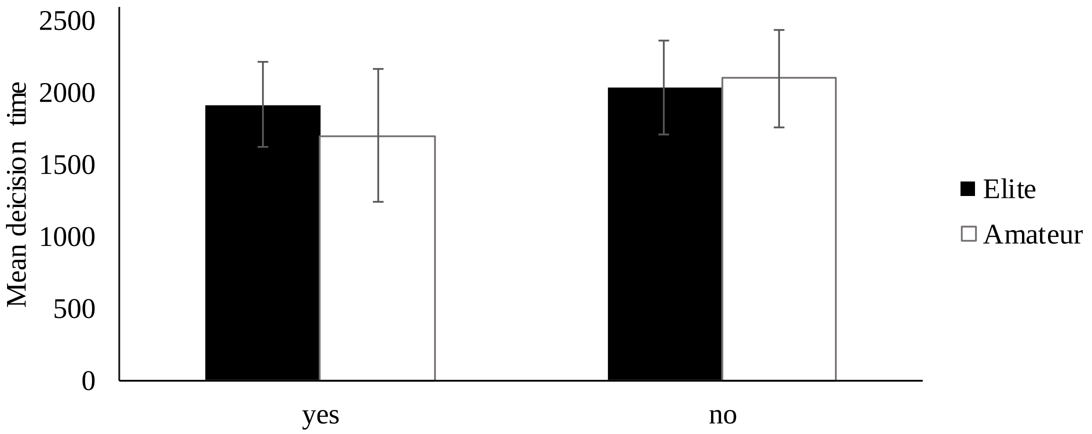


Figure 3.3. Decision time (in ms) and decision confidence (on Likert-type scale) of the selected (yes) and non-selected (no) best choice of elite and amateur players. Error bars indicate standard deviation.

Descriptive statistics of the *best choices* and related decision times and decision confidences are presented in Table 2.2 and Figure 3.3.The MANOVA analysis of whether the decision-making processes of elite and amateur players differed based on the *best choices* made (i.e., expertise × best choice interaction; Hypothesis 2b), did not show a main effect of *expertise* (Wilks's λ = 1.00, $F(1, 311) = 0.62$, $p = .538$), but revealed significant main effects of *best choice* (Wilks's λ = .91, $F(1, 311) = 15.19$, $p < .001$) and the *expertise* × *best choice* interaction (Wilks's λ = .97, $F(1, 311) = 5.27$, $p = .006$).

Following up the significant multivariate main effect and interaction, the subsequent univariate analyses for *decision time* showed significance in *best choice* ($F(1, 311) = 28.32$, $p < .001$, $\eta_p^2 = .101$) and the *expertise* × *best choice* interaction $F(1, 311) = 10.14$, $p = .002$, $\eta_p^2 = .032$). In detail, *t*-tests revealed significant faster decision times of when the *best choice* was selected compared to when it was not selected ($t(313) = 5.290$, $p < .001$, $d = 0.63$), and elite players showed slower *decision times* than amateurs when they selected the *best choice* ($t(102) = -2.840$, $p = .005$, $d = -0.60$). No between-group difference was revealed in the non-selected *best choice* $t(209) = 1.324$, $p = .187$, $d = 0.18$).

Univariate analyses for *decision confidence* revealed no significant affections of *expertise* $F(1, 311) = 0.76$, $p = .384$, $\eta_p^2 < .001$), *best choice* $F(1, 311) = 0.20$, $p = .656$, η_p^2 <

.001), and the *expertise* x *best choice* interaction $F(1, 311) = 1.49$, $p = .224$, $\eta_p^2 = .005$) (Tab 2.2., Fig. 3.3).

Discussion

Previous decision-making experiments were often either conducted without a motor response or with highly restricted micro-movements, challenging the ecological validity of the results obtained (Araújo et al., 2007; Mann et al., 2010; Travassos et al., 2013). With respect to these methodological issues, an in situ *embodied-choice* experiment with elite and amateur team-handball players was carried out. Thereby, current knowledge of expertise effects in decision making from an *embodied-choice* perspective (Lepora & Pezzulo, 2015; Raab, 2017a) was extend. Within the present study, it was looked at the *specific* and *best choices* players made, and the decision-making processes (i.e., decision time, decision confidence) underlying the elites' and amateurs' choices were also scrutinized.

Specific And Best Embodied Choices Are Expertise-Related

In line with the made assumptions, based on previous decision-making experiments with sport-specific motor responses (Magnaguagno & Hossner, 2020; van Maarseveen, Savelsbergh et al., 2018), an overall difference between expertise groups in the frequencies of the *specific choices* was found, showing highest frequencies for forward/tackling choices for the elite players, whereat amateurs chose passive/blocking most frequently.

Closer examinations of the differing frequencies of *specific choices* revealed a discrepancy in the choices of forward/tackling and passive/blocking between elite and amateur players, supporting expertise-specific decision making in sport (Araújo et al., 2017; Travassos et al., 2013). While sideways left and sideways right choices played a less important role for both groups alike, elite players chose forward/tackling more frequently (Δ 24.1 %) than amateurs, who chose passive/blocking more frequently (Δ 19.7 %). This implies a level-depending judgement of the need to intervene with an active defense action (i.e., forward/tackling) opposed to a passive one (i.e., passive/blocking). One reason for that can be found in the differing decision confidences between elite and amateur players in the passive/blocking choice. Elite players are significantly less confident (4.3 ± 1.2) than amateurs (4.8 ± 1.0) in this particular choice, indicating that more confidence seems to go along with less risk taking of amateurs, culminating in varying decisions between groups. Elite players seem to have perceived passive/blocking as riskier than a forward/tackling choice, because staying passive or blocking might allow the attacker to approach closer towards the goal, and duels in the own defense, near-goal area can be riskier. Therefore, elite players chose the rather active option of forward/tackling, to potentially prevent increasing pressure from the opponent attacker towards the goal. The hypothesis of higher confidence in elite players was not confirmed, but the fact that *specific choices* and decision confidence are linked confirms the connection of decision making performance confidence and first option, as demonstrated by Hepler and Feltz (2012) in basketball.

Furthermore, it was hypothesized, based on *simple heuristics* and *embodied-choice* research (Magnaguagno & Hossner, 2020; Raab, 2012; Raab & Laborde, 2011; van Maarseveen, Savelsbergh et al., 2018), to find higher quality of choices in elite players. This was confirmed by significant more frequent *best choices* of elite players in comparison to amateur players (Δ 24.9 %). In line with the obtained findings, a previous team-handball study did also find a higher correctness of responses by expert players (Magnaguagno & Hossner, 2020).

One reason for elite players making different and also better choices than amateurs might be due to their knowledge and experience with defensive tactics. The test instructions provided explanations about a man-to-man defense system the players had to see themselves put in. Certain rules within this defense system apply, which are taught in basic practice lessons from early team-handball ages on (Pabst & Scherbaum, 2018). With increasing age and expertise level, players not only practice more often and compete higher, they also learn and adapt defense systems further. Enhanced situation-specific learning effects foster the knowledge of response consequences (Raab, 2014), which can enable elite players to decide better in tactical situations.

Broadly speaking, the created performer environment setting that involves sport-specific motor responses was able to unfold expert decision-making differences within an in situ *embodied-choice* test. The obtained differences in *specific* and *best choice* demonstrated feasibility of a complex decision-making test in a multiple-choice, representative research design. Since cognitive and motor components of choices seem to be intertwined (Raab, 2017a), the sport-specific motor responses in this study include the interactions of both of the components, reflecting an athletes' actual decision-making performance better and accounting for ecological validity of the experimental representations (Araújo et al., 2007; Mann et al., 2010; Travassos et al., 2013). The results for *specific* and *best choice* confirm similar *embodied-choice* studies (Magnaguagno & Hossner, 2020; van Maarseveen, Savelsbergh et al., 2018), lending support to the general tenets of *embodied choices* (Raab, 2012).

Embodied Choices Of Elite Players Are Slower And Better

To increase the ecological validity of experimental findings in decision making, the in situ *embodied-choice* test offers possibilities to evaluate *what* (choices) and *how* (decision time) to act (Raab, 2017a). Here, the expertise differences in *specific* and *best choices* were analyzed, and how these choices were made. To do so, decision time and decision confidence were analyzed.

The general range of decision time data is similar to those from the in situ experiment in basketball (van Maarseveen, Savelsbergh et al., 2018), where the time of correct and incorrect decisions show equal proportions to the time data of the obtained *best choices*. This delivers support for the ecological validity of the experimental approach.

Most notably in the present study, slower decision times of *specific choices* (i.e. forward/tackling) and *best choice* of elite players were revealed, which stands in contrast to the assumptions of faster and more accurate decisions of better athletes from *simple heuristics* and decision-making research (Raab, 2012; Raab & Laborde, 2011; Travassos et al., 2013). The slower decision times of the elite players are possibly a result of *corrective* top–down processes interacting with bottom–up processes (Raab, 2014) of the sensorimotor system during decision making. *Corrective* interactions are action preparations of an athlete towards an opponent's action preference (top-down), however with ongoing course of the event, the final choice depends more on additional cues perceived in the unfolding action of the opponent (bottom-up). It was assumed that the players' *embodied choices* underly level-dependent *corrective* interactions during the decision-making processes, leading to slower, but therefore higher quality in decisions of elite players. Corrective interactions, as a dynamic function, may also rely on previous successful experiences (Raab, 2014).

Transferring this theory to the current test setting, the perceived kinematic cues of the approaching attackers in the videos, such as run-up speed and proximity to the defender, could first provoke an intuitive action preparation in the players (Raab & Laborde, 2011). Then, with ongoing time-motion course, the players perceive further kinematic cues of the attackers, such as preparing throwing kinematics or head movements, which seem to be judged differently by elite players and amateur players. Elite players could invest additional time within the top-down bottom-up control in order to 'wait-and-see' what choice would be the best in this particular moment. This means that apparently the quality of choices is prioritized above the speed.

A general phenomena in sports what underpins such time investments in favor for higher quality is the so-called *speed-accuracy tradeoff* (Schmidt & Lee, 2005), meaning that a more time-consuming evaluation of a situation can lead to higher success rates and fewer errors (Johnson, 2006). The slower but more frequent *best choices* by the elite players clearly indicate an expertise-related effect of speed-accuracy tradeoffs (Ratcliff et al., 2016) between both groups. Due to the elite players' extensive knowledge from increased training amount, higher competition levels, and (successful) experiences (Raab, 2014), this information seem to be processed during the top-down bottom-up interactions requiring longer processing times. Investigations on speed-accuracy tradeoffs in multiple-choice decision-making setups are rare, one investigation in rugby showed similar effects with a full-body interception or 'tackle' responses (Brault et al., 2012). Therefore, the detected slower decision times of the elite players in this study seem to be advantageous for the quality of the choices.

In a nutshell, the findings for decision time do not fully support previous research on *simple heuristics* (Raab, 2012). In fact, contrary to faster and better tactical choices of better players (Raab & Laborde, 2011; Travassos et al., 2013), the reverse relation between the *best choice* and *decision time* was illustrated. Supposedly, decision-making performance depends on factors such as decision time and confidence, meaning that better athletes apparently make better decisions but in a slower way. Assumably, decision time and confidence could play a more crucial and differential role in making *embodied choices*, underlining the necessity for further experiments within this framework.

Limitations

Despite the *embodied-choice* paradigm utilized for the design of a sport-specific environment, the number of choice options for the participants were limited to four, based on the technical possibilities of the test device itself. The experimental setup on the contact plate system represented team-handball specific dimensions, which contained only four respective contact plates located and accountable for the *embodied-choice* test. To further increase the validity of the paradigm, additional choices for the players would represent the individual choice of each player better. While the responses in the test are determined as linear movements, defending in game situations is always a unique event, since *context priors* and kinematic information impact anticipation and decision making (Gredin et al., 2020) constantly. For this reason, movements are not always linear, they rather follow a non-linear trajectory. Some players therefore showed first movement initializations for a forward/tackling choice, but by perceiving a 'mind-changing' cue in the attacker's ongoing action, the player changed his mind to decide for a sideways movement instead. Such a short-term change within the players' movement were not measured, but it indicated non-linearity of the motor execution of an embodied choice.

Implications

This study adds new insights to the understanding of *embodied choices* in sports, especially with respect to decision time and confidence.

For theory, the revealed results imply that decision-making research should henceforth consider not only *what* decisions are made, but also *how* these decisions are made in the same vein. Based on these results and general decision-making theories, decision time and decision confidence can be considered to better understand the decision-making processes in sports and beyond. This might help in specifying the exact mechanisms and existing theories applied in the sports context that do consider the decision-making process itself (not only the outcome), such as *simple heuristics* (Raab, 2012).

In particular, the decision time proportions in this study revealed that elite players made better but slower *embodied choices*. In the sense of a speed-accuracy trade-off, they seemed to prioritize the quality. This finding has important applied implications: If speed-accuracy plays a role in sport-specific *embodied choices*, players and coaches should focus more on the accuracy of a choice in defense decisions.

For the applied field, it is recommended that 'close-to real-world' experimental set-ups such as the in situ *embodied-choice* test presented here could be applied as a tactical training tool in team-handball and other team-sports. Similarly, a row of longitudinal 3D-video-based interventions to train team-handball tactics were conducted in the past (Raab et al., 2008). Results demonstrate improvements in tactical decision-making of players, facilitated by 3D-presentations of attack situations. Possibly, the in situ *embodied-choice* test presented here, that has been shown to produce reliable outcomes (Hinz et al., 2021), will be used in a similar fashion to improve tactical decision-making training in sports and the *embodied choices* of players in the future.

Conclusion

In summary, the chapter presented demonstrated the importance of capturing motor responses and the considerations of decision time and decision confidence in expert anticipation and decision-making experiments. The in situ *embodied-choice* test revealed differences in choices between elite and amateur team-handball players, confirming expertise-related decision making behavior (Magnaguagno & Hossner, 2020; Raab, 2012; Travassos et al., 2013). and extending recent knowledge in decision making research with regard to *embodied choices* (Magnaguagno & Hossner, 2020; van Maarseveen, Savelsbergh et al., 2018). Slower decision times for *specific* and *best choices* were found, which is in contrast to experts' faster and better choices in other sport studies (Raab & Laborde, 2011; Travassos et al., 2013). Therefore, possible explanations for the additional time investments by elite players to select a better *embodied choice* could be corrective top-down bottom-up interactions (Raab, 2014), and speed-accuracy tradeoffs (Ratcliff et al., 2016) in favor of accuracy. In general, fairly high decision confidences in both groups emphasize subjective accuracy of their decisions, but between-group confidence differences in particular choices (passive/blocking) point to the impact of confidence on decision-making performance. Together, this chapter provides further empirical evidence bearing up the *embodied-choice* framework (Lepora & Pezzulo, 2015) in sports and, especially, highlights the importance to better understand the mechanism underlying *embodied choices* such as through decision time and confidence.

Chapter 5

Epilogue

The final chapter contains a detailed aggregation of the findings of the work presented in this thesis. With reference to that, implications will be outlined for both theory and practice. Subsequently, certain limitations of the work will be discussed, and possible pathways for future research in the area of complex, motor-based diagnosing of anticipation and decision-making.

Aims of This Thesis

The aims of the present thesis were to create and evaluate a complex and representative, sensorimotor test which can assess anticipation and decision-making behavior and expertise in team-handball. In relation to the scientific controversy of how to diagnose expert anticipation and decision-making behavior and expertise (Farrow et al., 2005; Mann et al., 2007; Müller et al., 2015; Travassos et al., 2013), an effort was made to invent a sensorimotor test to assess perceptual-cognitive skills, which is based on the limitations and recommendations from previous examinations. A performance analysis tool was created that a) is reliable in the assessment of anticipation and decision making in a sport-specific performer environment, and b) that is sensitive enough to distinguish the anticipation and decision-making performances between players at elite and amateur skill level in team-handball. In detail, an attempt was made to set up a close-to-real-world environment with representative tasks, consisting of complex and near-game defense situations in team-handball that allows for performance measures of anticipation and decision-making parameters in a standardized test setup. To evaluate whether the created diagnostic tool meet the quality criteria of a new designed test, the thesis focused primarily on test reproducibility (Chapter 2) and test sensitivity/validity (Chapter 3). Secondary, this thesis also checked the diagnostic tool's transferability to current research areas (Chapter 3 and 4). For the first time in this very field of research, a test was created to determine the anticipation and decision-making performances of elite and amateur team-handball players, by utilizing varying team-handball attack and defense actions, and multiple sensorimotor actions as responses. Finally, the aims of this thesis were to check if the sensorimotor test provides reliable and valid test results, eligible for new perspectives on measuring expert anticipation and decision making in team-handball, and for team-sports in general.

Summary of Key Findings

After the evaluation of the designed representative, sensorimotor test, it can be stated that the test is a replicable and reliable diagnostic tool which allows for the determination of complex anticipation and decision-making behavior. The test was also proven to be sensitive enough to discriminate the decision-making behavior between varying expertise levels in team sports athletes. Moreover, by the application of current research models from sport psychology and cognition science, the complex nature and the near-game test character brought new insights in expert decision-making mechanisms to light, when multiple embodied responses are regarded in an experiment.

In the first study (Chapter 2), the first stage of this work attempted to develop a near-game performer environment with representative tasks constraints (Travassos et al., 2013), in the form of a) a coupled perception-action setup on a pressure-sensitive contact plate system, with b) varying attack sequences on a projection screen, and c) defense actions as multiple-choice responses. In the second stage, intra- and inter-session analyses of the defense response frequencies in video pairs, collected in test retest sessions, were conducted. Overall moderate agreement of the motor responses with the majority of attack situations were revealed, laying the cornerstone for the second and third study.

The execution of the second study (Chapter 3) took up the determined test reliability with the subsequent goal to apply group comparisons between elite and amateur team-handball players for evaluations for test sensitivity and its discriminant capability. In relation to distinct anticipation and decision-making skills of expert and near- or nonexpert players in the literature (Magnaguagno & Hossner, 2020; Mann et al., 2007; Travassos et al., 2013), the obtained expertise-related decision-making performances in the second study outline the discriminating and sensitive function of the representative, sensorimotor test. Indications are given, how sensorimotor interactions of the cognitive and the motor system affect tactical behavior (Raab, 2014), when visual information is restricted.

In the third study (Chapter 4), the process of decision making and its underlying mechanisms were scrutinized from an *embodied-choice* perspective (Lepora & Pezzulo, 2015), and with *take-the-best* examinations (Gigerenzer et al., 1999; Raab, 2012) from a *cognitive approach* perspective. The application of an in situ *embodied-choice* test revealed differences between elite and amateur team-handball players in *specific choices* (such as forward tackling; passive/blocking) and *best choices* (correct tactical response determined by external experts). For the first time in *simple heuristics* research (Raab, 2012), an expertise-related speed-accuracy tradeoff (Ratcliff et al., 2016) in favor for decision quality was identified, extending the concept of *simple heuristics* in sports (Raab, 2012) by involving key elements from *ecological dynamics* in terms of a robust performer– environment system and the linkage of perception and action (Araújo et al., 2017).

The previous section enumerated and recapitulated the key findings from the Chapters 2, 3, and 4. The following section will derive potential implications of the obtained results. Finally, limitations of this work as well as directions for future research will be discussed.

Theoretical Implications

From a theoretical point of view, this thesis presents a methodological concept which was created with respect to current theories and models from anticipation and decision-making research. The achieved reliable and discriminating psychometric properties of the created test enable secured statements to the theoretical contributions of the findings to research.

Reliability of Complex Perceptual-Cognitive Performance

The approach of a detailed exploration of the reliability of anticipation performance in terms of response frequency in study 1 (Chapter 2) brought to light, how dynamic and fluctuating the anticipation behavior across an unfolding action actually is. Most TO studies with reliability assessments calculated a single value to classify the overall reliability of all data

(Brenton et al., 2019; Gabbett et al., 2007; Loffing, Hagemann et al., 2015; Williams et al., 2002), often with acceptable levels of reliability. However, the individual inspection of occlusion points regarding reliable responses demonstrates partly contrary results. Despite the overall moderate level of response agreements in study 1, individual reliability measures, were lowest in the middle of the unfolding actions (occlusion points $t_4 – t_2$) across all types of attack actions. Therefore, the level of response agreement in individual occlusion time points could be a useful indicator for scientists not only to have a more profound picture of anticipation performances of athletes, but also to identify the critical time points of an opponent's unfolding action where the insecurity of an athletes' or players' appropriate tactical response is highest. Given the low numbers of TO studies with reliability assessments (Brenton et al., 2019; Gabbett et al., 2007; Loffing, Hagemann et al., 2015; Williams et al., 2002), and the knowledge gained from study 1, it appears helpful for TO studies in anticipation in sports to carry out reliability analyses, in order to enhance the experimental quality and to use it as a further performance indicator.

Visual information, such as kinematic cues, were shown to have a decisive impact on the correct prediction of the to-be-anticipated action, mostly assessed by the manipulation of the visual content in video sequences with the TO paradigm (Jones & Miles, 1978), and allowing for derivations of cue-usage strategies of athletes. Since there was no determination of correct or incorrect predictions in study 1 or study 2, no conclusions can be drawn about the quality of the anticipation (study 1), and decision-making behavior (study 2) of the players in both studies. Nevertheless, it can be assumed that the kinematic cues in the unfolding movements in each of the four attack actions in study 1 were perceived as representative and sport-specific enough by the players, what ultimately lead to overall reliable, and individual response patterns in the four different actions in study 1.

The impact of kinematic information on the distinct decision-making behavior between elite and amateur players in study 2 can closely be related to the model of Müller and Abernethy (2012) and Morris-Binelli and Müller (2017) from striking sports, illustrating that athletes' processing priorities seem to fluctuate depending on the task-relevance of the perceived information available. The model states that experts in sports are more aware of task-relevant information and its reliability for inferred response accuracy. This would explain why the elite players defended left-handed attackers significantly different than the amateur players, by weighing the kinematic cues of the left-handed attacker differently than the amateur players for making an other tactical decision. This is in line with the findings on hand-depending kinematic cues and their related tactical decisions (Jackson et al., 2006; Johnston & Morrison, 2016), and on the experience and tactical knowledge (Raab, 2014) of how to act when facing either a left- or a right-handed opponent. The question if the elite players decide better in the defensive scenario in the TO test cannot be answered, however, it can be stated that they decide differently, underpinning the discriminative power of the created test. A contribution is made from the team-sports domain to the striking sports model of Müller and Abernethy (2012), what was recommended by Gredin et al. (2020) in their review on current developments in anticipation research in sport.

With reference to the statement of Araújo et al. (2006) that decision-making behavior is an emergent behavior under constraints, the impact of context information on the players' behavior (Gredin et al., 2020) was attempted to minimize by the provision of identical oral instructions about the players body height, body mass and tactical preferences in all three studies. As Cordovil et al. (2009) found in their on-field study in basketball, the provision of players with either neutral, low-, or high-risk tactical instructions, and the facing of defenders with varying body height changes the attack patterns during offensive phases during play. With respect to main aims of this thesis, specific context information which were relevant for the experimental task, were provided but kept stable. The individual anticipation and decision-making behavior of the players in this thesis has to be regarded as one that emerged under the specific context information provided. It is possible that the behavioral patterns of the players change with further adjustments of the context information.

Advantages of Synthesizing the Ecological Dynamics and Cognitive Approach

The concept of this thesis made use of key elements from the *cognitive approach* and *ecological dynamics* from decision-making research that should enhance the ecological validity of the data (Araújo, et al., 2007, 2017; Mann et al., 2010), with respect to current developments in sports psychology and for having a more combined approach for the understanding of perceptual-cognitive mechanisms. As the *cognitive approach* is often experimentally-orientated using paradigms such as the in situ or the TO paradigm (Jones & Miles, 1978), *ecological dynamics* contains assumptions of representative task designs (Araújo et al., 2006) and that perception and cognition is embodied (Araújo et al., 2017; Raab & Araújo, 2019). To the best of knowledge, this is the first laboratory work that considered these elements with a high degree of changing task complexity, created by the number of representative attack and defensive actions in a performer environment (ecological dynamics), embodied response methods (*ecological dynamics*; *cognitive approach*), and the consideration of situational time pressure in tactical decision making (*ecological dynamics*; *cognitive approach*).

From a methodological point of view, the test design used in this thesis allows for the application of current models, such as SMART-ER (Raab, 2014) or the *embodied-choice* framework (Lepora & Pezzulo, 2015), in which response/decision time, response/decision accuracy, and decision confidence can be measured as essential indicators for complex decision-making behavior in multiple choice assessments (Ratcliff et al., 2016; Seale-Carlisle et al., 2019).

The involvement of sensorimotor interactions in the anticipatory and decision-making processes in all three studies allows for the evaluation if these interactions are either beneficial or detrimental on performance. The findings in study 1 show that anticipation and decision-making performance underlying the interaction of top–down and bottom–up processes in the cognitive and motor system in complex, time-pressured tactical situations can be considered as an emerging and reliable behavior. For the first time in the literature, evidence regarding the psychometric properties of sensorimotor interactions in anticipation and decision-making experiments is provided, what previous examinations with similar research approaches in team-sports did not evaluated (Magnaguagno & Hossner, 2020; van Maarseveen, Savelsbergh et al., 2018). The distinct and expertise-related decision-making behavior in study 2 further indicates how sensory and motor interactions affect complex tactical behavior of team-handball players with different expertise-level, by increasing the degree of the experimental task complexity (pre-specification of multiple, tactical responses and utilization of a variety of attack actions) from the comparable sensorimotor study by Magnaguagno and Hossner (2020) in team-handball. However, in contrast to their study, study 2 could not assess if the impact of sensorimotor interactions is beneficial or detrimental on the players' performances due to a missing accuracy parameter in the test setup. Nevertheless, it revealed expertise-differences in the defending of left- or right-handed players in a sport-specific performer environment, confirming the findings from experiments with the *cognitive approach* (Hagemann, 2009; Loffing, Hagemann et al., 2015; Loffing, Sölter et al., 2015), and implicating that experts in sports are better able to access knowledge from long-term memory for accurate defending of left-handers and transforming it into a motor response. Indications are given that there might be a difference in decision quality due to pronounced offensive-orientated defensive behavior in the elite players, but external ratings of the tactical decisions by experts were not conducted.

The response/decision times measures also revealed the duration of the top–down and bottom–up processes in the cognitive and motor system. Of note, the response/decision times in study 1 and 2 with the TO paradigm (Jones & Miles, 1978) were globally faster than the response/decision times in study 3 with the in situ paradigm. As an in situ environment with sport-specific motor responses are determined as the most appropriate methodology in expert decision-making experiments (Travassos et al., 2013), the response/decision time measures in study 3 appear to depict a more valid picture of the time required by the cognitive and motor system to judge the observed moments constantly, and by sorting the perceived cues based on its validity.

Study 1 and 2 provide support for further modeling of decision-making processes in time-pressure situations with SMART-ER (Raab, 2014), as it offers possibilities for deeper clarifications of decision-making strategies (selective; competitive; consolidated; corrective; Raab, 2014) with heuristic test approaches.

Embodied Choices as Perspective for Decision-Making Research

With respect to the ongoing controversy in sports psychology and its current overlap of the *cognitive approach* and *ecological dynamics* to better understand the mechanisms underpinning perceptual-cognitive expertise, the application of the recent *embodied-choice* framework (Lepora & Pezzulo, 2015) in study 3 combined the above mentioned opportunities to scrutinize decision-making behavior and expertise with the usage of sport-specific motor responses in an in situ environment (*ecological dynamics approach*) with heuristic decision rules (*cognitive approach*) underlying sensorimotor interactions (*ecological dynamics*/*cognitive approach*).

The application of the *embodied-choice* framework (Lepora & Pezzulo, 2015) revealed partly contrary results to what was found in several heuristic studies in sports (see Raab, 2012 for a review). Previous assumptions of higher decision quality and speed of experts in sports were not confirmed (Raab, 2012; Raab & Laborde, 2011), as the elite players in study 3 showed significant slower but better decisions. It can therefore be assumed that the heuristic decision rules could work differently. As most heuristic experiments in sports were either conducted from a *cognitive approach* perspective in nonmotor experiments (Johnson & Raab, 2003; Musculus, 2018; Musculus et al., 2018; Raab, 2012; Raab & Johnson, 2007; Raab & Laborde, 2011), or in motor experiments with offensive scenarios in team-sports with focus on the influence of complexity on implicit or explicit learning on decision making (Raab, 2003), study 3 revealed new aspects of complex, motor heuristic decision making. That sensorimotor interactions could sacrifice the processing time of sensory and motor information in favor for decision accuracy, as suggested from findings in study 2 and other motor and in situ decision-making experiments (Brault et al., 2012; Mori & Shimada, 2013), further underpins the meaningfulness of the methodological considerations of the key elements from the *ecological dynamics* and *cognitive approach*, in order to enhance the validity of the experimental findings (Araújo, Passos et al., 2007; Araújo, Hristovski et al., 2017; Mann et al., 2010).

Despite the representative task design with the sport-specific motor responses and the in situ environment in study 3, the final verification of the detected speed-accuracy-trade-off by the elite players still remains open. In order to clarify the interpretability of this matter, additional computer-based tests or on-field examinations, as conducted in the studies of van Maarseven, Oudejans et al. (2018) and van Maarseveen, Savelsbergh et al. (2018) in basketball and soccer, could foster the final determination of decision-making behavior and expertise in team-handball, by either on-field small-sided games (van Maarseveen, Savelsbergh et al. (2018) with capturing the execution times, and the kinematic cues with eye trackers (as decisive components of the cue-validity in *take-the-first* or *take-the-best* strategies), or either with a computer-based video test as a comparative test (van Maarseven, Oudejans et al., 2018), what in sum would offer a more valid view on the actual on-field perceptual-cognitive skills of players and athletes.

Aggregating the thesis' evidence for theoretical contributions to the field of research, it can be stated that it seems worthwhile to obtain reliability measures in perceptual-cognitive experiments as a further indicator for decision-making performance, because the perception and judgement of complex kinematic information seems to be a non-linear, and therefore unstable, process in motor response experiments. Furthermore, the impact of context information should be regarded in examinations, at least to provide athletes and players with knowledge about related *dynamic* or *stable priors* in order to minimize a possible bias in behavior through that. It appears to be a fruitful endeavor to combine key elements of the *ecological dynamics* and the *cognitive approach* by considerations of sensorimotor interactions in perceptual-cognitive experiments. This allows not only for discriminating players and athletes with varying expertise based on their choices and its accuracy, but also that decision/response time is a directional indicator for the duration of sensorimotor interactions and their hampering or fostering effect on decision making performance. Ultimately, contributions are made to recent developments as well as established models and concepts in research, recommending the further exploration of embodied decision making and the underlying mechanisms underpinning perceptual-cognitive behavior and expertise.

Applied Implications

Implications for sport practice drawn from this work underpins the meaningfulness of perceptual-cognitive skills, such as anticipation and decision making. The understanding of how perceptual-cognitive skills can be detected, and how expert anticipators and decision makers can be shaped would have an important benefit for athletes of all age and gender groups, on all levels, for training and competition.

Performance analysis

Despite the widespread approach to detect talent and expertise across sports domains with individual considerations of performance-determining factors, such as physical, physiological, psychological, sociological, technical and tactical factors (Burgess & Naughton, 2010; Sarmento et al., 2018), this works emphasizes multidisciplinary performance analyses. Chapter 2 describes an approach for practitioners of how to create a performance analyses tool which unites most of these mentioned factors. The obtained variables in this work cover a broad scope of performance factors within one test setup, such as the technical (motor response time for defense action), psychological (decision confidence), and cognitive/tactical (response frequency) factors. In team-handball, there is only one similar test, which assessed team-handball performance with a multidimensional game-based performance test, developed on the basis of game-specific physiological, biomechanical variables and competition parameters (Wagner et al., 2016). The representative, sensorimotor test in this work pursues a similar goal, including also the cognitive mechanisms paired with tactical knowledge and the transformation into a physical response. The derivations that can be made from performance outcomes with this test can be useful to evaluate the understanding of tactical behavior of team-handball players, and it could provide coaches with feedback about the recent status of the tactical knowledge of their players in their individual stage of development.

Due to the standardized and repeatable test protocol, the captured response frequencies offer possibilities for coaches and practitioners to provide augmented (extrinsic) feedback to the players about their tactical as well as their movement quality. Augmented feedback comprises *knowledge of results* (e.g. tactical accuracy) *and knowledge of performance* (e.g. movement quality in terms of motor response time) (McRobert & Williams, 2019). Possible feedback regarding *knowledge of results* is verbalized after an action towards the environmental goal, and it could evaluate if the players' response frequencies within the provided tactical instructions by the coaches match with the tactical targets of the applied defense system. Feedback regarding *knowledge of performance* could evaluate the variable decision time as an informative indicator for the players' movement patterns of their defense actions itself. To provide qualitative feedback to the players regarding that, coaches are required to observe the nature of the unfolding movement plus using the achieved decision time as an empirical support for faster (or slower) biomechanical improvements of the motion (e.g. more effective body posture for motor response initialization).

Depending on the objective of the performance analyses, simple modifications of the test protocol of the representative, sensorimotor test could aim for the evaluation of perceptual-cognitive performance underlying physical load. In their review, Schapschröer et al. (2016) showed that the degree of the physical load affects the perceptual-cognitive performance of athletes. The physical load in the test protocol during performance analyses could either being modified by increasing the number of attack sequence and simultaneously reducing the break times between them, to a degree where players' attention and concentration will be affected (Klatt & Smeeton, 2021). Another possibility would be an involvement of intermittent movement exercises such as treadmill running during performance analyses sessions with the test (Frýbort et al., 2016; Smith et al., 2016). The results of the performance analyses can assist coaches or federations in the designs of individual or long-term training schedules with larger proportions of decision-making enhancing small-sided games (Davids et al., 2013; Travassos et al., 2012).

Chapter 2 and Chapter 3 implies the usefulness of multidisciplinary performance analyses tools, as it offers a realistic picture of an athletes' performance capabilities assessed under close-to-real world conditions. Additionally, implications are made for practitioners of how future, possibly modified, analyses tools can be set up for individual purposes.

Talent Identification and Development

As described in Chapter 3 and Chapter 4, the representative, sensorimotor test was proven to be sensitive enough to discriminate between different performance levels. Such multidisciplinary performance analyses tools are meanwhile indispensable components in talent identification and talent detection processes, being highly recommended by sports scientist in current research (Mann et al., 2017; Murr et al., 2018; O'Connor et al., 2016) for the application in practice.

As one of multiple definitions, the construct of 'talent identification' involves recognizing current participants with potential to elite performance, as stated in an early work by Régnier et al. (1993). Talent development describes the provision of athletes with an appropriate learning environment for the realization of talent (Abbott et al., 2002). To date, an evidence-based approach in sport psychological practice during talent identification and development is quite difficult to implement, as the development and the impact of perceptual-cognitive components are deemed to be a too complex construct (Höner et al., 2019). For this reason, the reliable and discriminant character of the representative, sensorimotor test would allow practitioners in the professional environment of an athlete a permanent implementation into the long-term talent identification and development procedures on a local, regional or national level.

In terms of talent identification, professional team-handball clubs who conduct performance analyses across the course of a full season could implemented this test as one component in their individual test batteries, for example at season start, during the winter break, and possibly before the decisive end phase of a season. Once, the test setup is established, new video sequences can be created at any time and implemented easily, so that coaches or users could create their tactical scenarios based on the coaches' or the clubs game philosophy.

The sports promotion system of team-handball federations could modify and implement a more practicable version of the test for their talent scout interventions in early ages. Ideally, potential players with an apparent distinction of anticipation and decision-making capabilities could be identified in an early maturation phase. So far, there is no consideration of assessing perceptual-cognitive skills in the scouting manual (Deutscher Handballbund e.V., 2022) for junior national team scoutings of the German Handball Association (Deutscher Handballbund). Practitioners, such as junior elite level coaches, sport psychologists or exercise scientists at Olympic training sites or youth academies could intensify the development of perceptual-cognitive skills of talented young athletes by process-related test usage on a permanent base (e.g. integration in training sessions; junior national team interventions). Meanwhile, several training facilities are in possession of a contact plate system, which means that the identical test setup can be installed location-independent by connecting a laptop (with the test program) with the local contact plate system.

Chapter 3 and 4 highlights that the sensitive character of the representative, sensorimotor test would suit into the talent identification process for team-handball federations, since there are no permanent diagnose tools for perceptual-cognitive skills yet. The constant evaluation of the decision-making behaviors of talented players opens the door for coaches to distinguish better from worse anticipators and decision makers, subsequently allowing for early identification of expert anticipation and decision-making capabilities in youth or junior age groups.

Perceptual-Cognitive Training

The *expert performance approach* (Ericsson & Smith, 1991) in this work clearly revealed gaps in the anticipation and decision-making capabilities between team-handball players (Chapter 3; Chapter 4). By detecting such gaps, various possibilities for perceptual-cognitive skill training are given which is determined as a relevant piece of talent development in sport (Loffing et al., 2017). There is a large amount of research on various approaches for perceptual-cognitive skills training, as presented in numerous studies and contributions (Causer & Williams, 2013; Larkin et al., 2015; McRobert & Williams, 2019; Williams et al., 2002). The overall aim of training should be the efficacy of retention and the transfer of envisaged learning effects from the training environment to on-field situations, which demands the methodological considerations of representative tasks in perceptual-cognitive skills training (Broadbent et al., 2015). The representative, sensorimotor test in this work seems therefore to be qualified as a suitable training intervention tool tailored for team-handball players. The game character of the test ensures a high level of similarity between training and real-life performance, facilitating specific tactical defense training to foster tactical competences as well. Additionally, the test system is open for domain-specific purposes for the user in the field, for example coaches can modify the instructions for either offense- or passive-orientated defense systems.

Chapter 3 and 4 illustrated that the time for making a decision seems to play a more crucial role in team sports than previously assumed. Thus, it appears as a worthwhile approach for training and competition to have a stronger focus on the quality of players' decision, rather than expecting the players to be fast *and* accurate instead. Chapter 3 clearly presents the dynamic shifting of tactical choices during the time course of an unfolding action of an attacker, implying the difficulty for the defender to identify the most accurate tactical response while underlying the time constraints of the one-on-one situation. Considering the findings from Chapter 3 and 4, implications are given that coaches can accord more time to elite players for choosing their best tactical responses, which seem to be a key element of their superior tactical behavior.

As an example from team-handball, the training study by Hohmann et al. (2016) conducted a video-based decision training in national youth team-handball teams under different video presentation conditions over a 6-week period. Also analyzing decision quality (first and best option) and decision time (time for first and best option), it was shown that the training interventions on the measurement site benefited in faster decision times when realistic video presentations were applied. However, responses by the team-handball players were given via keystroke. In relation to their approach, the amateur players in Chapter 4 in this work demonstrated fewer *best choices*, which were made faster. Long-term training interventions with the test in this work could help amateur players to improve strategic decision-making, especially because the sensorimotor interactions of top-down and bottom-up processes can be stimulated during the tactical training, and therefore schooled for the anticipation of the tactical response consequences in the heuristic decision-making processes (Raab, 2014). The results of a long-term training intervention including consideration of action responses can not only benefit players and coaches themselves, it could also generate further data for the limited number of pre- to post-retention test in perceptual-cognitive training research (Höner et al., 2019).

Evaluating the players' decision confidences could sustain the coaches' perception of the players' pick-up process of new tactical instructions during training, in particular, where potential uncertainties or knowledge gaps in tactical adaptions could be. As higher decision confidence is linked to better choices/options (Hepler & Feltz, 2012), and motor confidence (subjective estimation of the ability to execute a respective option) (Musculus, Raab et al., 2018), coaches could align the feedbacks from *knowledge of results* and *knowledge of performance* with the players' subjective perception of their actions. As an example, if a player responds too early with rather low confidence, but the tactical choice was right, a coach could take up the respective attack-defense sequence and identify players' doubts that affected the motor execution of the anticipated tactical response, therefore delaying the decision time (as discussed in Chapter 4).

Overall, seen from a practical perspective, the representative, sensorimotor test highlights its applicability for complex performance analyses procedures, as it involves several performance-discriminating factors in a realistic measurement environment. Furthermore, the potential is revealed for its implementation in talent identification and development processes in team-handball, on a broad sports basis and also on an elite performance level. The practicability and its user-friendliness enable the test as a fixed component in team-handball training.

Research Limitations and Future Research Directions

The process of designing and evaluating of the test in this work illustrates the methodological considerations that have to be made when creating a representative, sensorimotor test, and it extends expertise research in the field of *ecological cognition* (Araújo et al., 2017), and embodied decision making in sports. Within this process, a number of potential shortcomings in this work will be discusses in the upcoming paragraph, followed by suggestions for potential research questions in the future.

Limitations

From a methodological perspective, although Chapter 2 and Chapter 3 displays the dynamic change of preferred tactical response over the occlude time course of the four attack actions, the major limitation of this thesis is a temporal decoupling between events of the screen and the sport-specific movement responses of the players.

During the theory-based design of the test, the creation of the TO test protocol was based on previous TO studies, that captured the participants' responses after the end of a stimuli presentation (Loffing & Hagemann, 2014; Loffing, Hagemann et al., 2015; Loffing, Sölter et al., 2015) Additionally, due to the technical limitations in the data processing of the contact plate system, it was not possible to apply in situ conditions in the TO protocol, where players could have responded right away during the stimuli presentation. This implies that the given motor responses of the players in this work are not of a situated nature, occurring as a direct result of the information processing. To counteract this issue, the instructions were provided to the participants to follow their first intuition when giving a motor response. However, following the first intuition while suppressing the underlying motor response seem to be two oppositely running processes, which can affect the dynamic top-down and bottom-up interactions in the sensory and cognitive system (Raab, 2014). The decoupling of video presentation and motor responses is a rather artificial component of the test setup, not completely representing real-world constrains. Giving a later motor response could encourage deliberate decisions, affecting the decision outcome in Chapter 2 and 3. Instead, intuitive decision making, also linked to faster decision time, seem to result in higher decision quality (Raab & Laborde, 2011). The transfer to actual on-field performances of the players is to be interpreted with care, more suitable for that would be Chapter 4 with the coupled in situ motor responses.

Given the practical realities of the contact plate system, the representative, sensorimotor test only allowed for four defense response-related contact plates. Despite the possibility for multiple-choice responses in this test compared to previous studies which used less response options (Brenton et al., 2019; Cocić et al., 2021; Gabbett et al., 2007; Loffing, Hagemann et al., 2015; Williams et al., 2002), the full scope of the movement range of defense actions is still not fully covered. Magnaguano and Hossner (2020) used a coordinate system capturing the defense actions of the players in their study, which gives a more detailed estimation about individual movements. But neither the domain-specific defense action that was executed was determined as such (when was a tackling move identified as such), nor the response times were recorded. Even though the study design in this and their work are of similar fashion, they both highlight the methodological difficulties when measuring complex anticipation and decision making. Notwithstanding, the provision of four tactical response options (in Chapter 2 and Chapter 3) or *specific choices* (in Chapter 4) exposes a very specific insight in possible on-field defending behavior, due to the practical conception of the test.

Further clarifications are needed about the external validity of the representative, sensorimotor test. So far, the test was proven for reliability and test sensitivity, however, it still remains unclear if the findings in this work correlate with the perceptual-cognitive performances of players in actual on-field situations of play.

From a practical perspective, the influence of anthropometrical, physical or technical characteristics of the attacker, also stated as performance-discriminating contextual features in team-handball (Wagner et al., 2014), on the players' decision-making performances, are not investigated. With respect to this matter and for test construction reasons, the instructions to the players regarding these context factors were standardized and not varied, in order to minimize a bias in the decision-making patterns. A taller attacker with distinct action preferences while attacking could cause a different pattern in the defense behavior. It is of note that the sub-sample characteristics in Chapter 3 and Chapter 4 also comprises intra-individual differences within the elite and amateur group itself. A maturation effect and its influence on expertise and knowledge could facilitate heteroscedasticity within the obtained data, which was detected in the field-hockey study by Morris-Binelli et al. (2021).

From a general perspective, it must be mentioned that the design and evaluation process in this work was constantly accompanied by terminological hurdles to identify relevant literature. This was applicable for the theory-based conception of the test, and for the classification of the findings into existing literature as well. First, there is a detected discrepancy in *expert performance approach* (Ericsson & Smith, 1991) studies, as there is a broad variety of terminological determinations of expertise levels (e.g. experts, high performers, elite-level, Olympic-level, and so on). Several authors already pointed to this matter, recommending a common usage of terms to classify expertise level, in order to ensure the methodological quality of studies through better comparability of findings (Scharfen & Memmert, 2019; Swann et al., 2015). Second, the ongoing debate amongst sport psychologists and cognition scientists about best-fit models for the explanation of anticipation and decision making rather hampers the overall fulfillment of the methodological expectations from both research fields. The book chapter *Embodied Cognition* by Löffler et al. (2020) contrasts classic, psychological perspectives on perception, action and cognition with recent developments of embodied cognition in sports. The broad variety of scientific approaches, for example perception-action coupling (Dicks et al., 2019; Huesmann et al., 2021), visual-perceptual-motor skill approaches (Müller & Rosalie, 2019), *embodied choices* (Lepora & Pezzulo, 2015), or the SMART-ER model (Raab, 2014), just to name a few, gives a glimpse of how complex the field of perceptual-cognitive research, in particular anticipation and decision making, actually is. For this reason, the general interpretation of the findings in this work depends from the individual point of view and the context of the reader.

Future Research Directions

The work in this thesis laid down an experimental framework for measuring expert decision-making behavior. Additional domain-specific probabilistic information in terms of *context* (*stable* and *dynamic*) *priors* (Gredin et al., 2020) should be integrated into the attack sequences in the video stimuli. *Stable priors* about action preferences of the attacker, for example preferences for long-range throws from distance or one-on-one duels (Helm et al., 2020; Lüders et al., 2020) or varying tactical systems (Levi & Jackson, 2018) could be modified in the test protocol. *Dynamic priors*, such as a changing game time and score board could constantly be included in the visual display during the test (Farrow & Reid, 2012), reinforcing the team-handball specific task constraints for the players, and ultimately increasing the representativeness of the test. Such adaptions could qualify the representative, sensorimotor test for future examinations in the field of the Bayesian integration framework for sports, which investigates how decisions are made, based on many possible decision outcomes in an uncertain world (Körding, 2007).

To check for the external validity of the test, future examinations could conduct on-field examinations with a notational system in team-handball play, to correlate the empirical results from the laboratory with those from the field. Van Maarseveen, Oudejans et al. (2018) used a notational system for the determination of actual perceptual-cognitive performance during on-field situations of play, consisting of detailed expert ratings regarding individual attack and defense actions during 3 vs. 3 small sided games. The scouting manual of the German Handball Federation (Deutscher Handballbund e.V., 2022) applies different basic and team play situations, in which players' decision-making performances are rated on a subjective expert level. These basic and team play situations would form a baseline for a novel, empiric notational system that can be used for validity evaluations of the test in this work.

As this work presents divergent results for decision (or response) time, showing an absence of faster decisions by elite players (Chapter 3), or even a speed-accuracy trade-off in favor for accuracy in the elite players (Chapter 4), future investigations should consider putting the focus also on the contributions of decision time on the performance outcomes. As complex motor experiments, dealing with speed-accuracy trade-offs, are less to find in perceptual-cognitive research (Belkin & Eliot, 1997; Brault et al., 2012; Hinz et al., 2022; Mori & Shimada, 2013), the phenomenon of speed-accuracy trade-offs was not investigated yet in complex, heuristic decision-making studies. Results from such experiments could extend knowledge from *simple heuristic* studies, which were mostly conducted in nonmotor experiments (Raab, 2012).

The multidisciplinary approach of this thesis, involving combined performance aspects of athletes, provides a far-sighted contribution to new research disciplines, such as performance science, currently evolving in sports psychology (Raab, 2017b). Performance science integrates elements from performance psychology with other disciplines such cognition science, applicable on the overlap of psychological and cognitive research interests on expert performance. The representative, sensorimotor test can serve as a basic tool for future research for the endeavor to exactly predict human behavior in sports, or to provide knowledge for talent predictions. As Markus Raab, current president of the European Federation of Sport Psychology (FEPSAC) states, the topic 'Mind and Motion' will remain a central aspect in sport psychology till the year 2050, which is why this work is as fruitful contribution to future inter-disciplinary examinations.

Concluding Remarks

In conclusion, the findings in this thesis provides a methodological approach to create a multidimensional diagnose tool that can assess expert perceptual-cognitive skills in team-handball. The design and the evaluation of the test has addressed a number of controversial issues in current sport psychology and cognition science, with respect to methodological considerations when assessing (expert) perceptual-cognitive behavior. The current thesis addresses key elements from the *ecological dynamics* and the *cognitive approach* in order to conceive a test method that enables to explain complex sport behavior from a holistic view.

The theory-based test construction involved key aspects such as a representative task design (Araújo et al., 2006) in which cognition and perception is embodied (Raab & Araújo, 2019), culminating in a perceptual-cognitive skill test with sport-specific attack-defense scenarios requiring complex motor response behavior. The reliable and performance-discriminating quality attributes of the representative, sensorimotor test lay the foundation for well-founded insights in expert anticipation and decision making in team sports. The test was used to show the dynamics of decision-making processes while underlying visual constraints, outlining how anticipatory information modulates the decision outcome in a complex performer environment. Revealed expertise effects in decision-making behavior imply that sensorimotor interactions, occurring within the sensory and cognitive system during making tactical decisions, run differently in players from elite and amateur playing level, what ultimately affects the types of decision and their particular decision time. Further tests carried out with an *embodied-choice* approach (Lepora & Pezzulo, 2015) provide indications for an expertise-related speed-accuracy trade-off from elite players, who seem to sacrifice decision speed for decision accuracy when motor components are involved in heuristic decision making.

More broadly, this thesis provides a solid foundation for future developments in sport psychology. As perceptual-cognitive research nowadays combines elements from sports psychology, performance science and cognition science in an inter-disciplinary way, the findings in this thesis extends recent state-of-the-art in the literature, presenting methodological implications for future examinations and application possibilities in the field.

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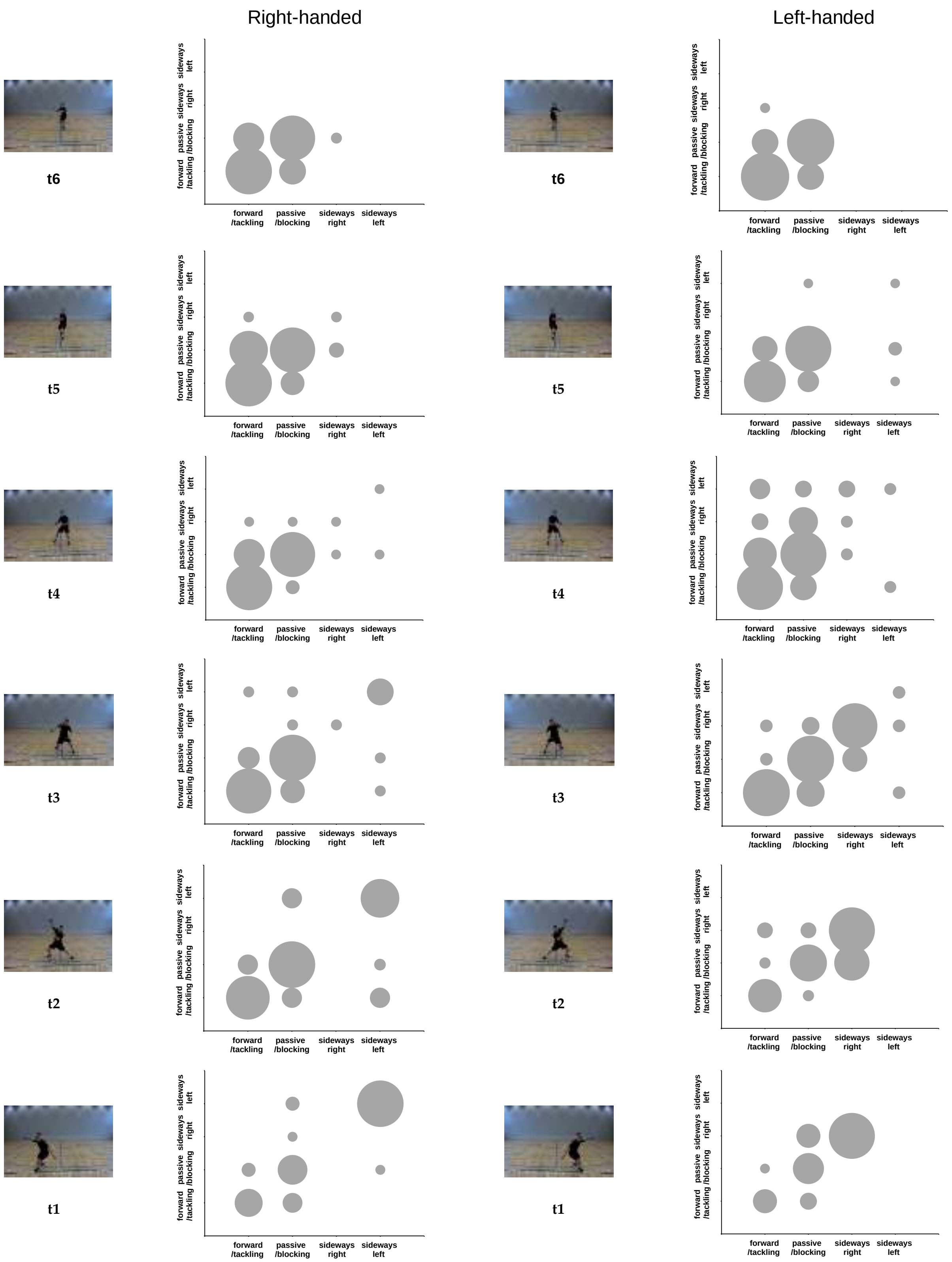
Appendices

Supplemental Material



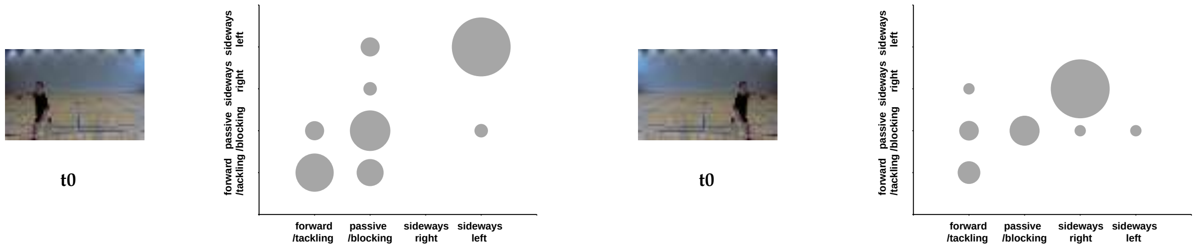
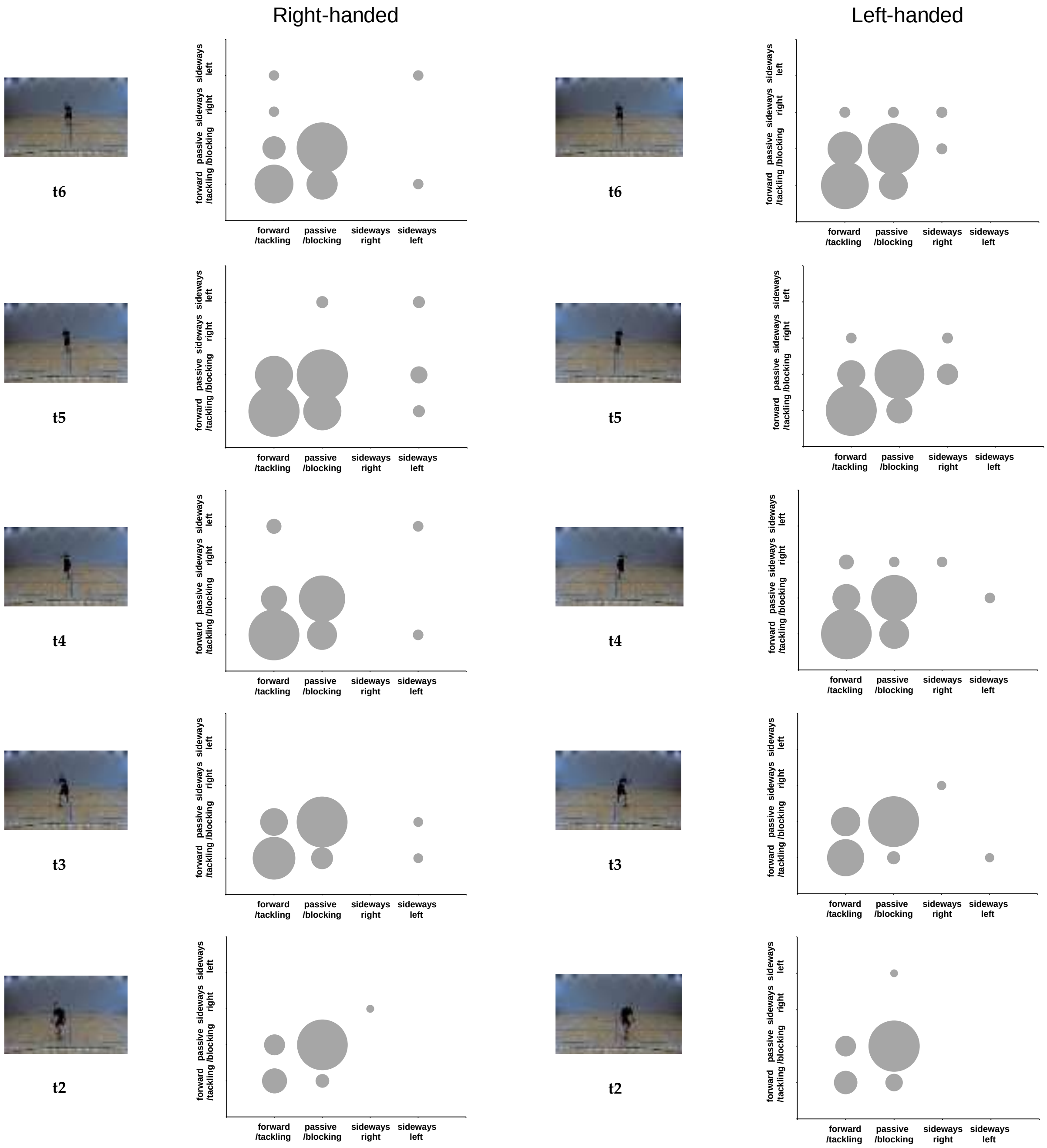


Figure A. Response distribution and consistency of *choices of motor response* (doubled videos; intra-session) in Breakthrough.



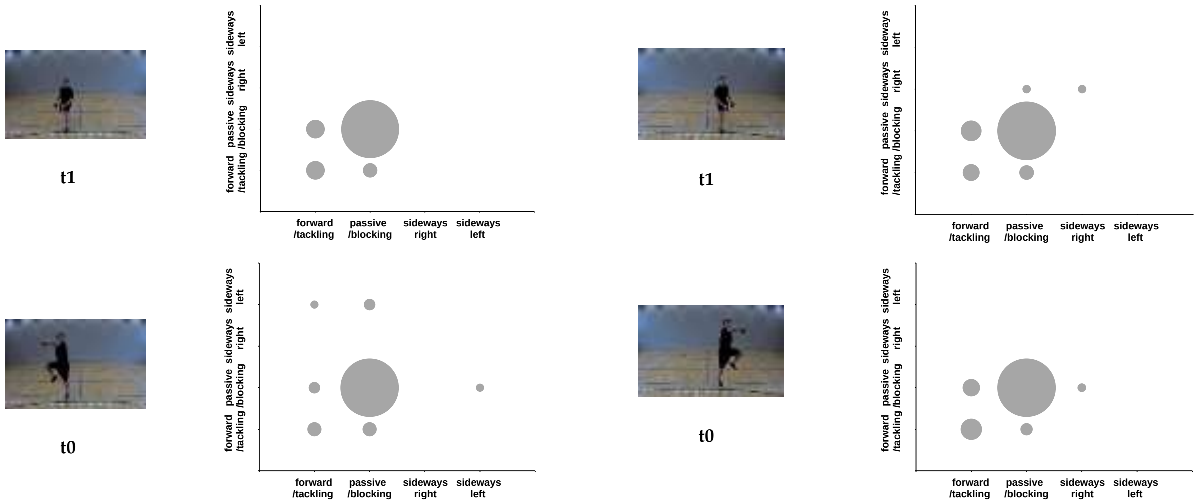
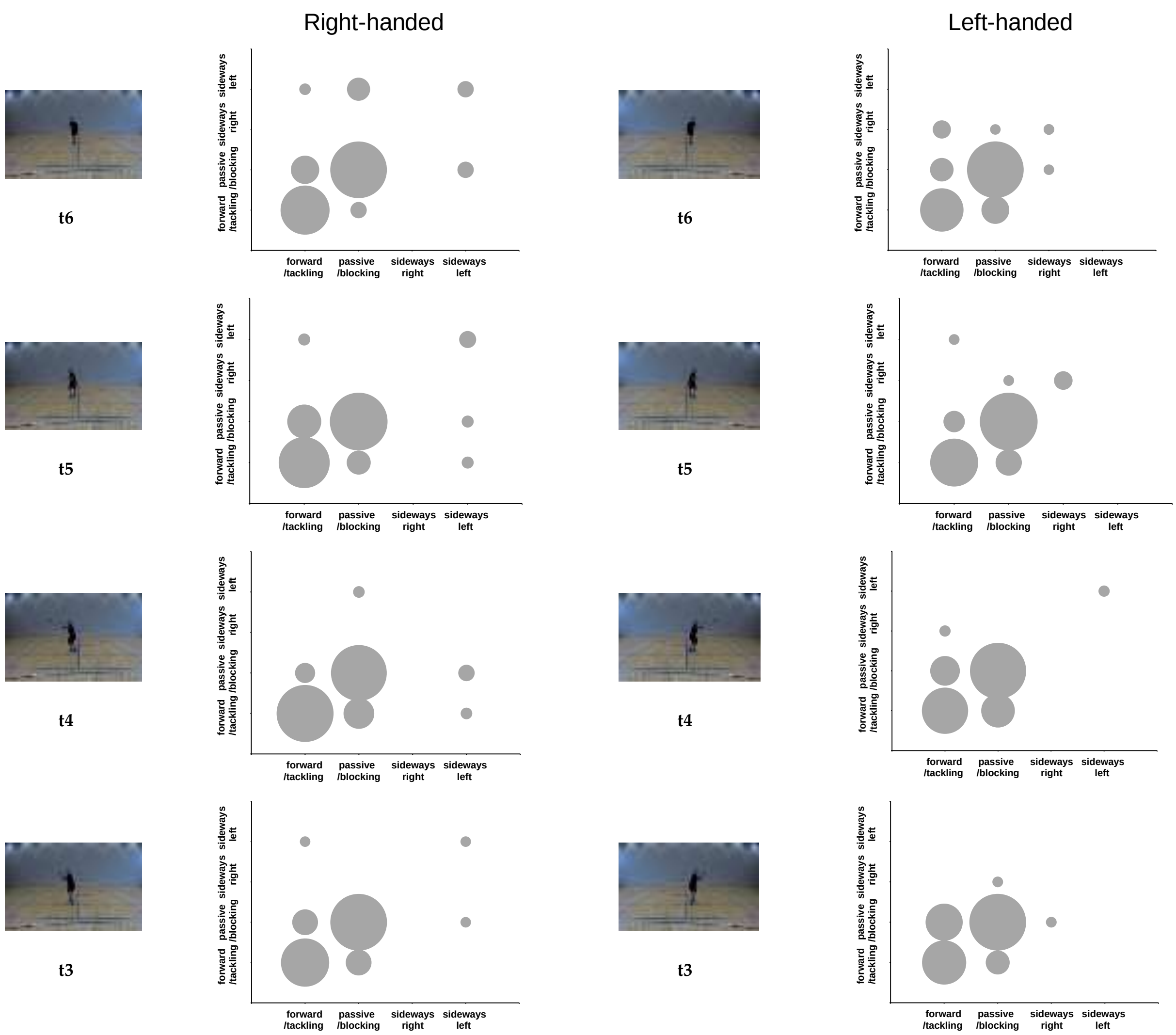


Figure B. Response distribution and consistency of *choices of motor response* (doubled videos; intra-session) in Jump throw.



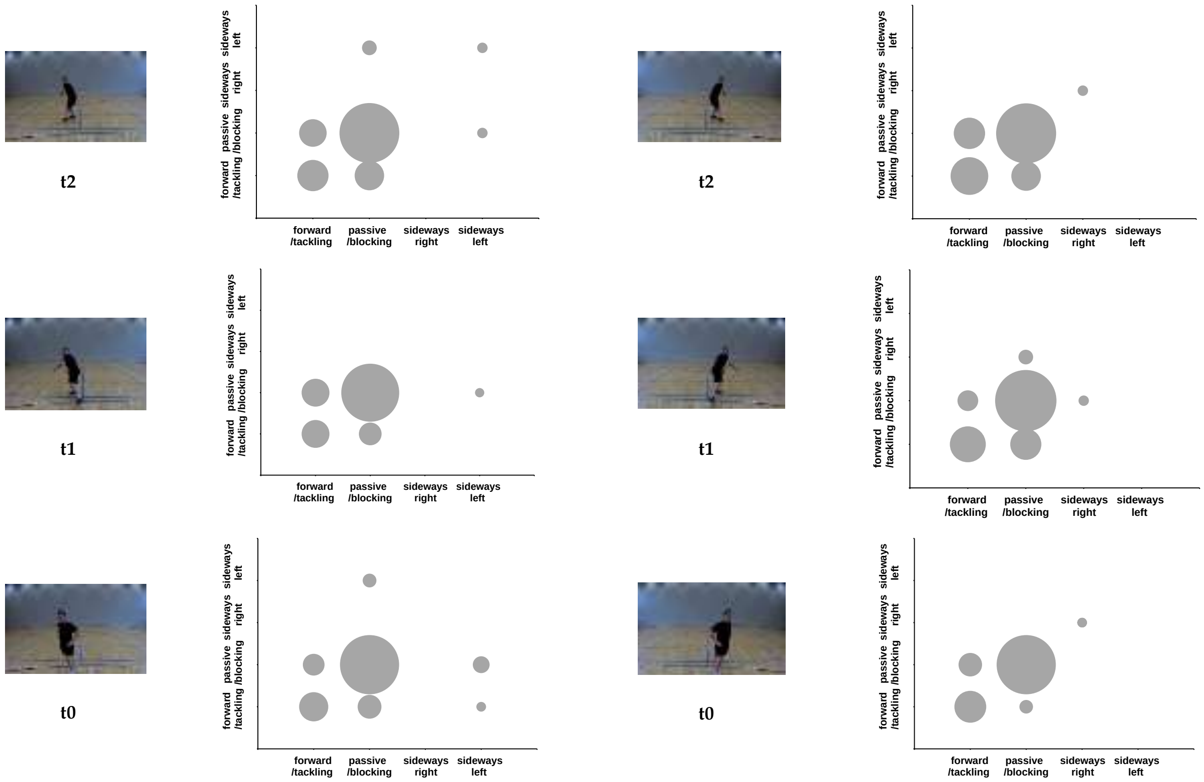
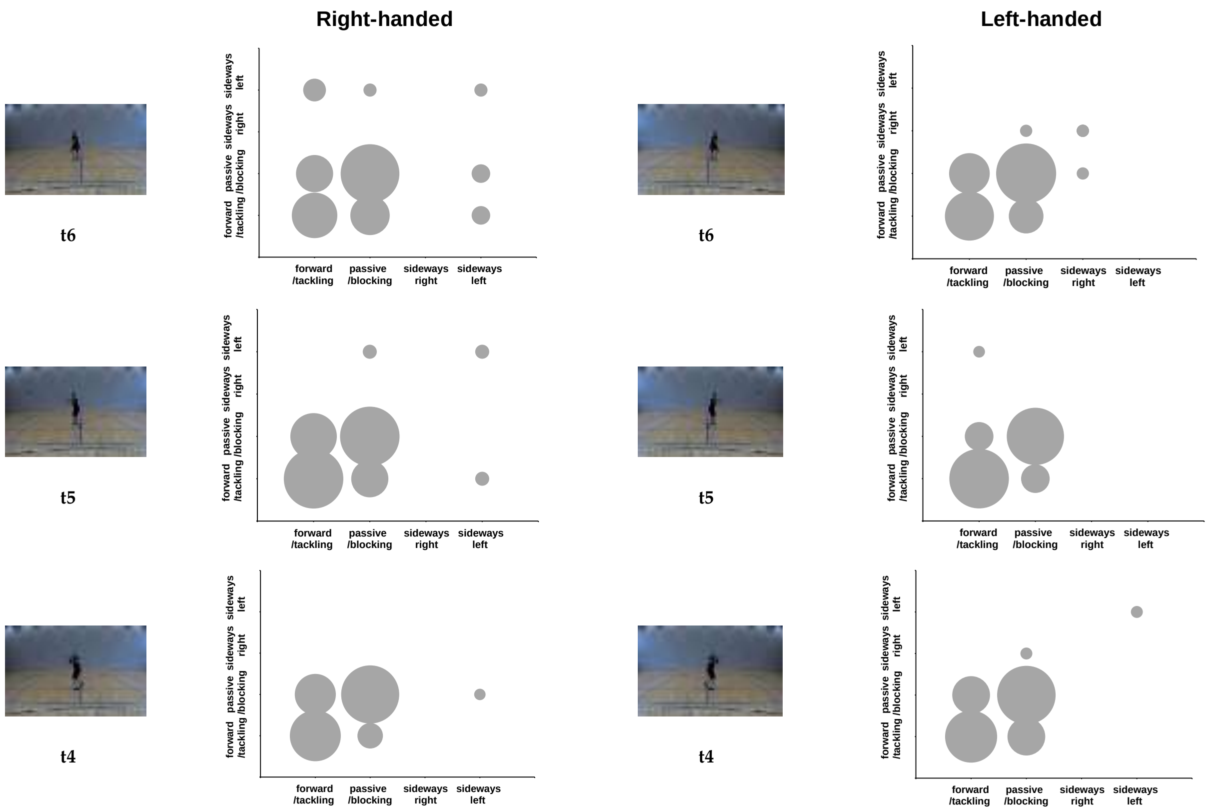


Figure C. Response distribution and consistency of *choices of motor response* (doubled videos; intra-session) in Standing throw.



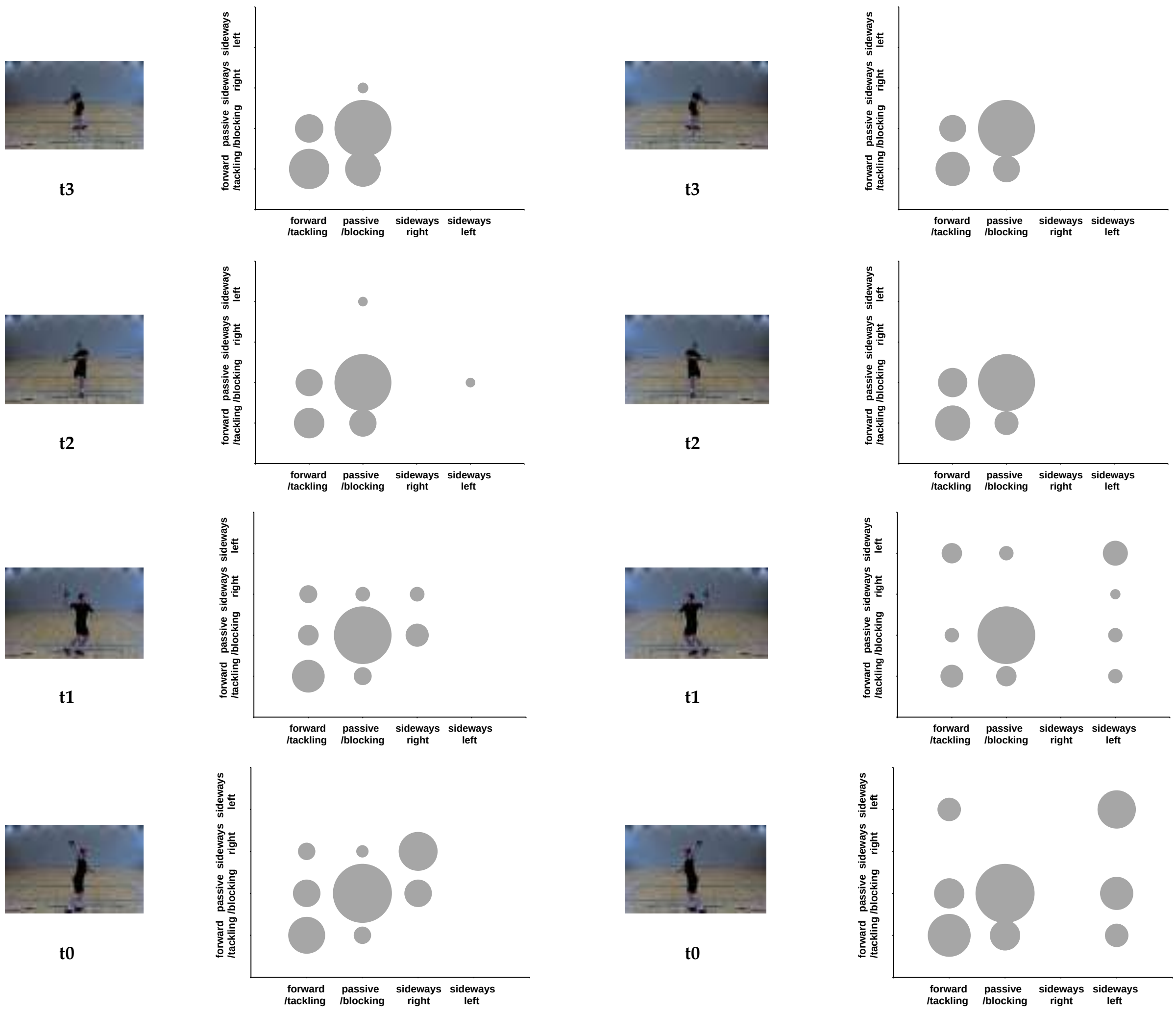
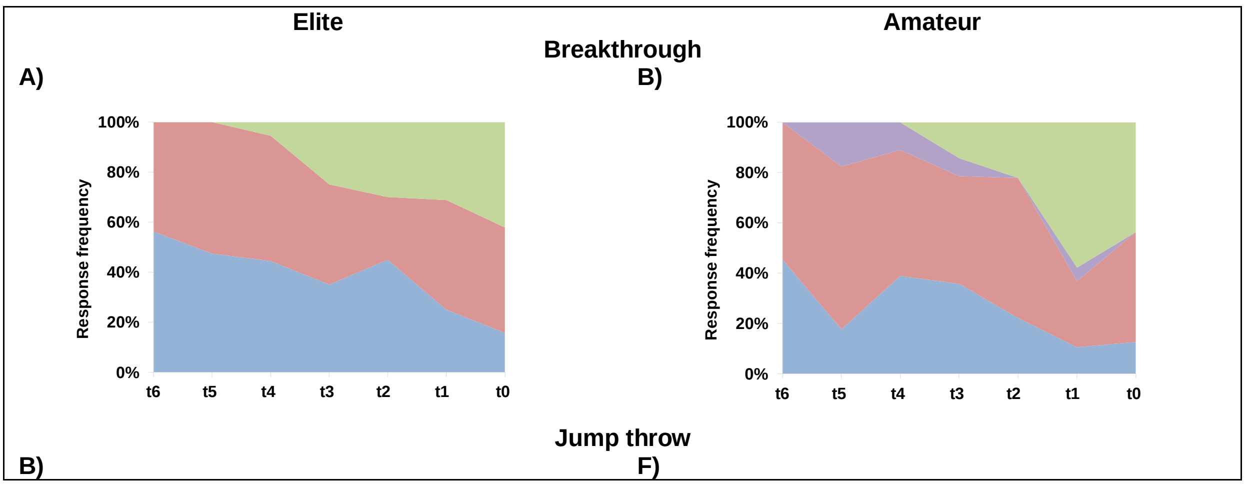


Figure D. Response distribution and consistency of *choices of motor response* (doubled videos; intra-session) in Pass.



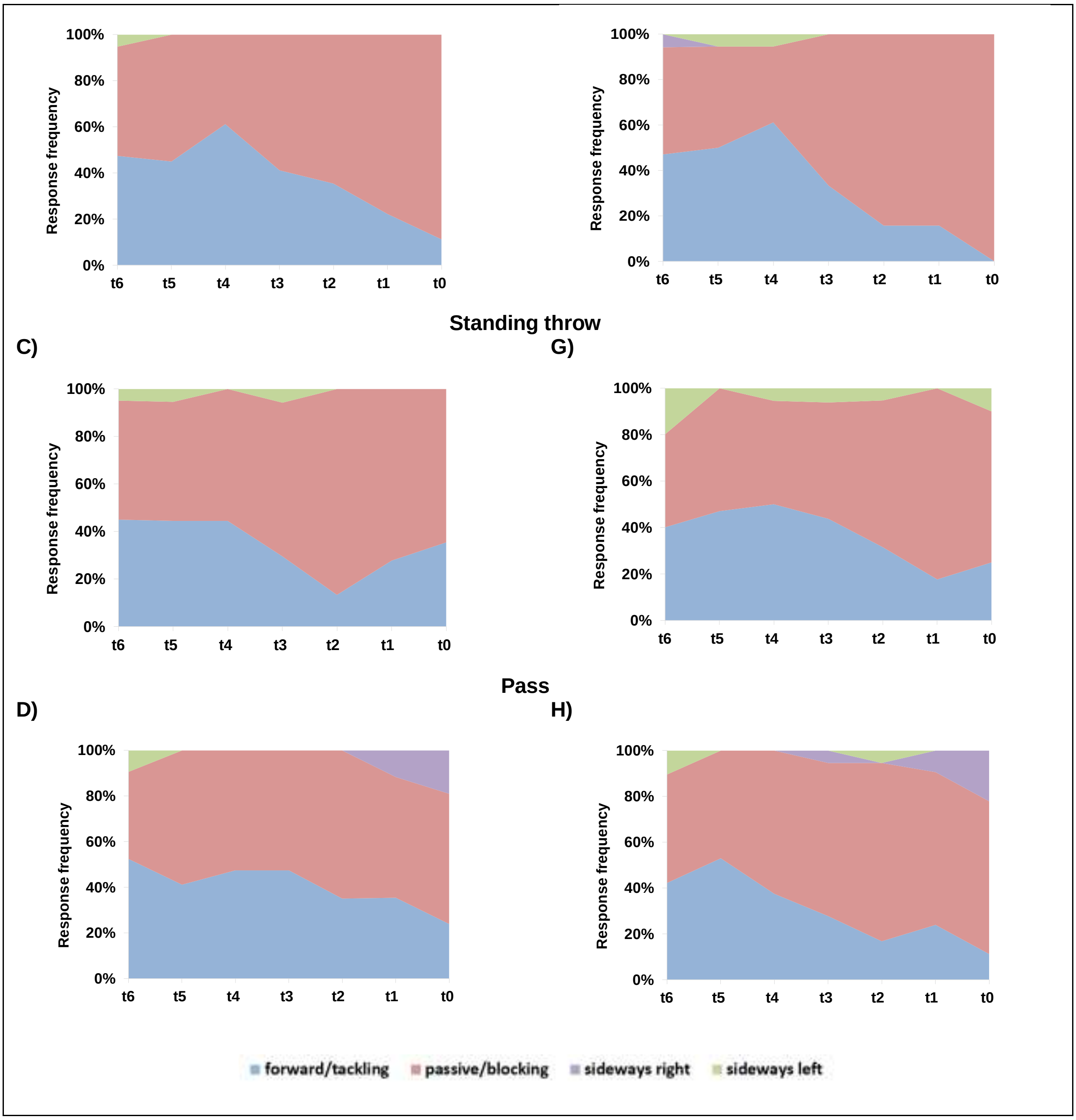


Figure E. Frequency distributions of motor responses on all right-handed attacks of elite (left) and amateur players (right) over occlusion time points. Stacked area graphs show occlusion points (*x*-axis) and response frequency (*y*-axis), dotted areas indicate significant higher between-group frequency. Colored areas in the graphs illustrate the respective response distribution over time in the elite (A-D) and amateur (E-H) player group.

Table A1.

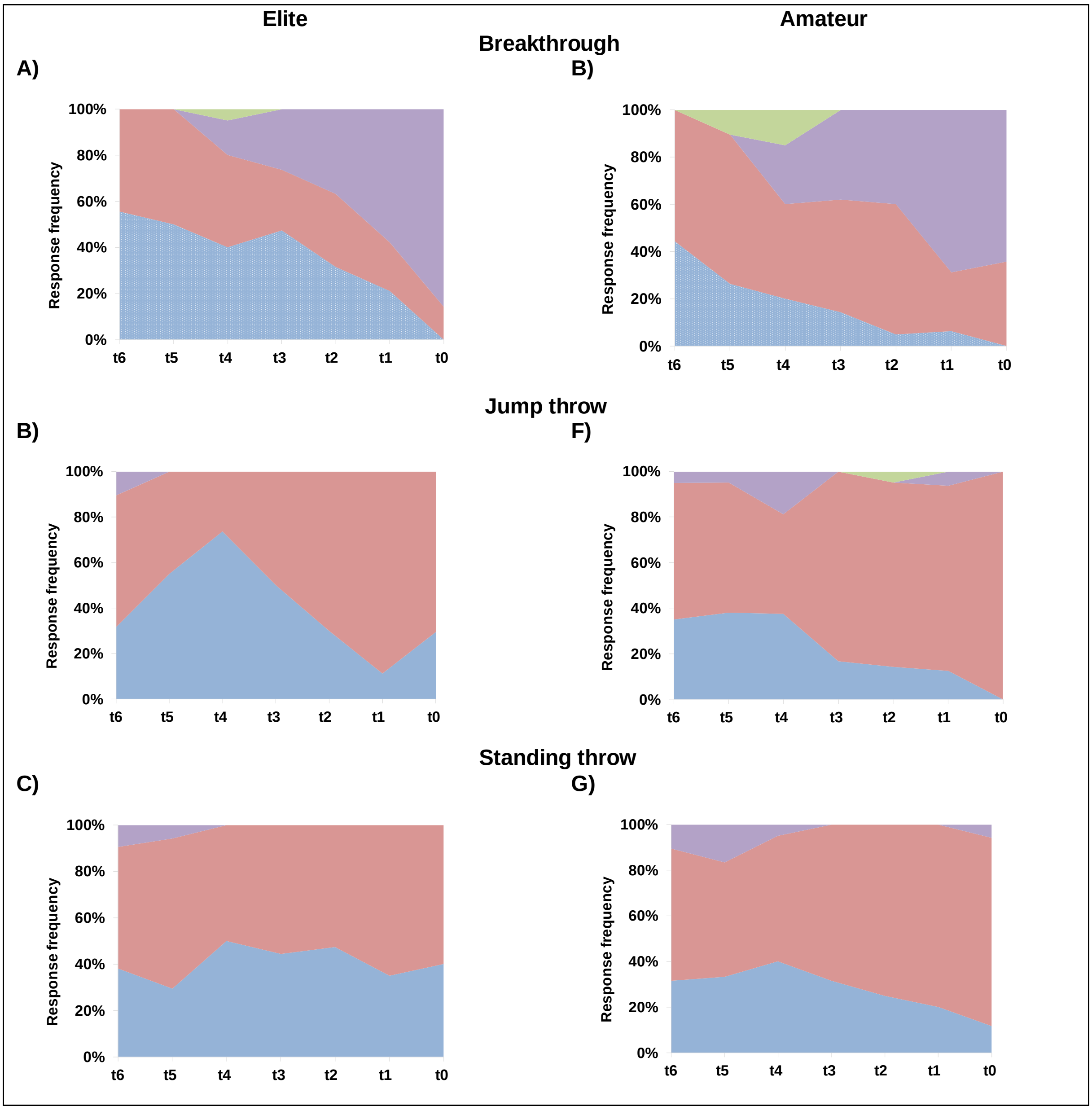
Elite-amateur player comparisons for response frequency at each occlusion time point (t_6-t_0) in all right-handed attacks (BT=Breakthrough, JT=Jump throw, ST=Standing throw, PA=Pass).

		t6	t5	t4	t3	t2	t1	t0
BT								
	Passive/ blocking	$\chi^2(1)$ = 0.43, *p* = .511,	$\chi^2(1)$ = 0.54, *p* = .463,	$\chi^2(1)$ = 0.00, *p* = 1.000,	$\chi^2(1)$ =0.28, *p* = .868,	$\chi^2(1)$ = 3.70, *p* = .054,	$\chi^2(1)$ = 1.17, *p* = .279,	$\chi^2(1)$ = 0.00, *p* = .955,

		$\varphi = .11$	$\varphi = .12$	$\varphi = .00$	$\varphi = .03$	$\varphi = .31$	$\varphi = -.18$	$\varphi = -.01$
	Forward/ tackling	$\chi^2(1) = 0.43$, $p = .511$, $\varphi = -.11$	$\chi^2(1) = 3.57$, $p = .059$, $\varphi = -.32$	$\chi^2(1) = 0.11$, $p = .735$, $\varphi = -.06$	$\chi^2(1) = 0.02$, $p = .966$, $\varphi = .01$	$\chi^2(1) = 2.18$, $p = .139$, $\varphi = -.24$	$\chi^2(1) = 1.28$, $p = .258$, $\varphi = -.19$	$\chi^2(1) = 0.12$, $p = .727$, $\varphi = -.06$
	Sideways left	n.a.	n.a.	$\chi^2(1) = 1.03$, $p = .310$, $\varphi = -.17$	$\chi^2(1) = 5.81$, $p = .447$, $\varphi = -.13$	$\chi^2(1) = 2.96$, $p = .587$, $\varphi = -.09$	$\chi^2(1) = 2.46$, $p = .115$, $\varphi = .27$	$\chi^2(1) = 0.03$, $p = .955$, $\varphi = -.01$
	Sideways right	n.a.	$\chi^2(1) = 3.66$, $p = .056$, $\varphi = .32$	$\chi^2(1) = 2.12$, $p = .146$, $\varphi = .24$	$\chi^2(1) = 1.47$, $p = .225$, $\varphi = .21$	n.a.	$\chi^2(1) = 0.87$, $p = .352$, $\varphi = .16$	n.a.
JT								
	Passive/ blocking	$\chi^2(1) = 0.00$, $p = .985$, $\varphi = -.00$	$\chi^2(1) = 0.42$, $p = .516$, $\varphi = -.11$	$\chi^2(1) = 0.12$, $p = .729$, $\varphi = -.06$	$\chi^2(1) = 0.23$, $p = .631$, $\varphi = .08$	$\chi^2(1) = 1.82$, $p = .177$, $\varphi = .23$	$\chi^2(1) = 0.25$, $p = .618$, $\varphi = .08$	$\chi^2(1) = 2.00$, $p = .157$, $\varphi = .24$
	Forward/ tackling	$\chi^2(1) = 0.00$, $p = .985$, $\varphi = -.00$	$\chi^2(1) = 0.10$, $p = .758$, $\varphi = .05$	$\chi^2(1) = 0.00$, $p = 1.000$, $\varphi = .00$	$\chi^2(1) = 0.23$, $p = .631$, $\varphi = -.08$	$\chi^2(1) = 1.82$, $p = .177$, $\varphi = -.23$	$\chi^2(1) = 0.26$, $p = .618$, $\varphi = -.08$	$\chi^2(1) = 2.00$, $p = .157$, $\varphi = -.24$
	Sideways left	$\chi^2(1) = 0.92$, $p = .337$, $\varphi = -.16$	$\chi^2(1) = 1.14$, $p = .285$, $\varphi = .17$	$\chi^2(1) = 1.03$, $p = .310$, $\varphi = .17$	n.a.	n.a.	n.a.	n.a.
	Sideways right	$\chi^2(1) = 1.15$, $p = .284$, $\varphi = .18$	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
ST								
	Passive/ blocking	$\chi^2(1) = 0.40$, $p = .525$, $\varphi = -.10$	$\chi^2(1) = 0.03$, $p = .862$, $\varphi = .03$	$\chi^2(1) = 0.44$, $p = .505$, $\varphi = -.11$	$\chi^2(1) = 0.73$, $p = .393$, $\varphi = -.15$	$\chi^2(1) = 2.38$, $p = .123$, $\varphi = -.27$	$\chi^2(1) = 0.51$, $p = .476$, $\varphi = .12$	$\chi^2(1) = 0.00$, $p = .985$, $\varphi = .00$
	Forward/ tackling	$\chi^2(1) = 0.10$, $p = .749$, $\varphi = -.05$	$\chi^2(1) = 0.02$, $p = .877$, $\varphi = .03$	$\chi^2(1) = 0.11$, $p = .738$, $\varphi = .06$	$\chi^2(1) = 0.73$, $p = .392$, $\varphi = .15$	$\chi^2(1) = 1.55$, $p = .213$, $\varphi = .21$	$\chi^2(1) = 0.51$, $p = .476$, $\varphi = -.12$	$\chi^2(1) = 0.47$, $p = .495$, $\varphi = -.11$
	Sideways left	$\chi^2(1) = 2.06$, $p = .151$, $\varphi = .23$	$\chi^2(1) = 0.97$, $p = .324$, $\varphi = -.17$	$\chi^2(1) = 1.03$, $p = .310$, $\varphi = .17$	$\chi^2(1) = 0.00$, $p = .965$, $\varphi = .01$	$\chi^2(1) = 0.81$, $p = .367$, $\varphi = .16$	n.a.	$\chi^2(1) = 1.80$, $p = .180$, $\varphi = .22$
	Sideways right	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
PA								
	Passive/ blocking	$\chi^2(1) = 0.35$, $p = .114$, $\varphi = .09$	$\chi^2(1) = 0.47$, $p = .492$, $\varphi = -.12$	$\chi^2(1) = 0.35$, $p = .557$, $\varphi = .10$	$\chi^2(1) = 0.76$, $p = .385$, $\varphi = .14$	$\chi^2(1) = 0.75$, $p = .386$, $\varphi = .14$	$\chi^2(1) = 0.74$, $p = .389$, $\varphi = .14$	$\chi^2(1) = 0.37$, $p = .542$, $\varphi = .10$

Forward/ tackling	$\chi^2(1) = 0.42$, $p = .516$, $\varphi = -.10$	$\chi^2(1) = 0.47$, $p = .492$, $\varphi = .12$	$\chi^2(1) = 0.35$, $p = .557$, $\varphi = -.10$	$\chi^2(1) = 1.51$, $p = .219$, $\varphi = -.20$	$\chi^2(1) = 1.64$, $p = .200$, $\varphi = -.21$	$\chi^2(1) = 0.60$, $p = .438$, $\varphi = -.13$	$\chi^2(1) = 1.06$, $p = .303$, $\varphi = -.17$
Sideways left	$\chi^2(1) = 0.01$, $p = .916$, $\varphi = .02$	n.a.	n.a.	n.a.	$\chi^2(1) = 1.14$, $p = .285$, $\varphi = .17$	n.a.	n.a.
Sideways right	n.a.	n.a.	n.a.	$\chi^2(1) = 1.09$, $p = .298$, $\varphi = .17$	n.a.	$\chi^2(1) = 0.05$, $p = .823$, $\varphi = -.04$	$\chi^2(1) = 0.06$, $p = .807$, $\varphi = .04$

Note. Between-group differences are reported as chi-square statistics (χ^2; *p*) and the corresponding effect size φ. Fischer calculation method was not applicable due to non-consistent directional differences in response frequency between the groups. Non available (n.a.) comparisons reflect that the respective motor response did not occur in neither group.



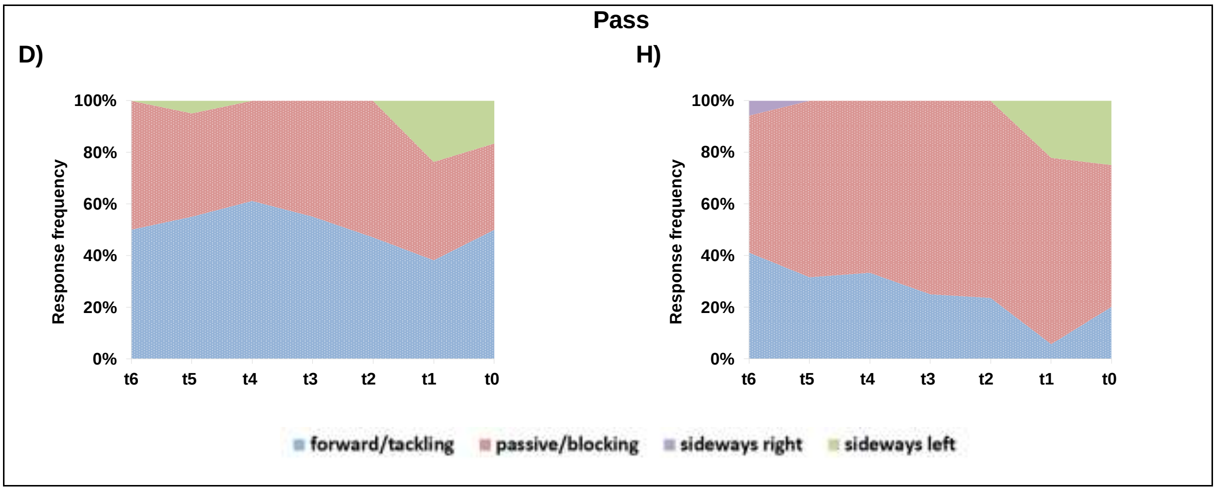


Figure F. Frequency distributions of motor responses on all left-handed attacks of elite (left) and amateur players (right) over occlusion time points. Stacked area graphs show occlusion points (*x*-axis) and response frequency (*y*-axis), dotted areas indicate significant higher between-group frequency. Colored areas in the graphs illustrate the respective response distribution over time in the elite (A-D) and amateur (E-H) player group.

Table B1.

Elite-amateur player comparisons regarding response frequency at each occlusion time point (t_6-t_0) in all left-handed attacks (BT=Breakthrough, JT=Jump throw, ST=Standing throw, PA=Pass).

	t6	t5	t4	t3	t2	t1	t0	*p*
BT								
Passive/ blocking	$\chi^2(1) = 0.44$, $p = .505$, $\varphi = .11$	$\chi^2(1) = 0.69$, $p = .408$, $\varphi = .13$	$\chi^2(1) = 0.00$, $p = 1.000$, $\varphi = .00$	$\chi^2(1) = 1.93$, $p = .165$, $\varphi = .22$	$\chi^2(1) = 2.17$, $p = .140$, $\varphi = .24$	$\chi^2(1) = 0.32$, $p = .858$, $\varphi = .03$	$\chi^2(1) = 1.71$, $p = .190$, $\varphi = .25$	-
Forward/ tackling	$\chi^2(1) = 0.44$, $p = .505$, $\varphi = -.11$	$\chi^2(1) = 2.31$, $p = .129$, $\varphi = -.24$	$\chi^2(1) = 1.91$, $p = .168$, $\varphi = -.22$	**$\chi^2(1) = 5.20$, $p = .023$, $\varphi = -.36$**	**$\chi^2(1) = 4.67$, $p = .031$, $\varphi = -.35$**	$\chi^2(1) = 1.76$, $p = .189$, $\varphi = -.22$	n.a.	**.033**
Sideways left	n.a.	$\chi^2(1) = 2.22$, $p = .136$, $\varphi = .24$	$\chi^2(1) = 1.11$, $p = .292$, $\varphi = .17$	n.a.	n.a.	n.a.	n.a.	-
Sideways right	n.a.	n.a.	$\chi^2(1) = 6.25$, $p = .429$, $\varphi = .13$	$\chi^2(1) = 0.63$, $p = .427$, $\varphi = .13$	$\chi^2(1) = 0.41$, $p = .839$, $\varphi = .03$	$\chi^2(1) = 0.18$, $p = .676$, $\varphi = .07$	$\chi^2(1) = 1.71$, $p = .190$, $\varphi = -.25$	-
JT								
Passive/ blocking	$\chi^2(1) = 0.02$, $p = .894$, $\varphi = .02$	$\chi^2(1) = 0.61$, $p = .437$, $\varphi = .12$	$\chi^2(1) = 1.17$, $p = .279$, $\varphi = .18$	**$\chi^2(1) = 4.50$, $p = .034$, $\varphi = -.35$**	$\chi^2(1) = 0.67$, $p = .414$, $\varphi = .13$	$\chi^2(1) = 0.39$, $p = .530$, $\varphi = -.11$	**$\chi^2(1) = 6.80$, $p = .009$, $\varphi = .43$**	-
Forward/ tackling	$\chi^2(1) = 0.05$, $p = .821$, $\varphi = .04$	$\chi^2(1) = 1.18$, $p = .278$, $\varphi = -.17$	**$\chi^2(1) = 4.64$, $p = .031$, $\varphi = -.36$**	**$\chi^2(1) = 4.50$, $p = .034$, $\varphi = .35$**	$\chi^2(1) = 1.48$, $p = .224$, $\varphi = -.19$	$\chi^2(1) = 0.20$, $p = .900$, $\varphi = .02$	**$\chi^2(1) = 6.80$, $p = .009$, $\varphi = -.43$**	-

	Sideways left	n.a.	n.a.	n.a.	n.a.	$\chi^2(1)$ = 0.98, *p* = .323, φ = .15	n.a.	n.a.	-
	Sideways right	$\chi^2(1)$ = 0.42, *p* = .517, φ = -.10	$\chi^2(1)$ = 0.98, *p* = .323, φ = .15	**$\chi^2(1)$ = 3.90, *p* = .048, φ = .33**	n.a.	n.a.	$\chi^2(1)$ = 1.16, *p* = .282, φ = .19	n.a.	-
ST									
	Passive/ blocking	$\chi^2(1)$ = 0.03, *p* = .867, φ = .03	$\chi^2(1)$ = 0.77, *p* = .380, φ = -.15	$\chi^2(1)$ = 0.10, *p* = .758, φ = .05	$\chi^2(1)$ = 0.65, *p* = .420, φ = .13	$\chi^2(1)$ = 2.82, *p* = .093, φ = .28	$\chi^2(1)$ = 0.12, *p* = .914, φ = .02	$\chi^2(1)$ = 2.20, *p* = .138, φ = .24	-
	Forward/ tackling	$\chi^2(1)$ = 0.30, *p* = .585, φ = -.09	$\chi^2(1)$ = 0.06, *p* = .803, φ = .04	$\chi^2(1)$ = 0.39, *p* = .536, φ = -.10	$\chi^2(1)$ = 0.65, *p* = .420, φ = -.13	$\chi^2(1)$ = 1.27, *p* = .260, φ = -.19	$\chi^2(1)$ = 1.64, *p* = .200, φ = -.21	$\chi^2(1)$ = 3.72, *p* = .054, φ = -.32	-
	Sideways left	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	-
	Sideways right	$\chi^2(1)$ = 0.00, *p* = .959, φ = .01	$\chi^2(1)$ = 1.01, *p* = .316, φ = .17	$\chi^2(1)$ = 0.92, *p* = .336, φ = .16	n.a.	n.a.	n.a.	$\chi^2(1)$ = 1.21, *p* = .272, φ = .18	-
PA									
	Passive/ blocking	$\chi^2(1)$ = 0.03, *p* = .858, φ = .03	$\chi^2(1)$ = 3.17, *p* = .075, φ = .29	$\chi^2(1)$ = 2.79, *p* = .095, φ = .28	$\chi^2(1)$ = 3.75, *p* = .053, φ = .31	$\chi^2(1)$ = 2.06, *p* = .151, φ = .25	**$\chi^2(1)$ = 4.54, *p* = .033, φ = .34**	$\chi^2(1)$ = 0.18, *p* = .180, φ = .22	**.013**
	Forward/ tackling	$\chi^2(1)$ = 0.29, *p* = .591, φ = -.09	$\chi^2(1)$ = 2.17, *p* = .140, φ = -.24	$\chi^2(1)$ = 2.79, *p* = .095, φ = -.28	$\chi^2(1)$ = 3.75, *p* = .053, φ = -.31	$\chi^2(1)$ = 2.06, *p* = .151, φ = -.25	**$\chi^2(1)$ = 5.78, *p* = .016, φ = -.39**	$\chi^2(1)$ = 3.79, *p* = .052, φ = -.32	**.001**
	Sideways left	n.a.	$\chi^2(1)$ = 0.96, *p* = .323, φ = -.16	n.a.	n.a.	n.a.	$\chi^2(1)$ = 0.01, p = .907, φ = -.02	$\chi^2(1)$ = 0.40, *p* = .529, φ = .10	-
	Sideways right	$\chi^2(1)$ = 1.21, *p* = .272, φ = .18	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	-

Note. Between-group differences are reported as chi-square statistics (χ^2; *p*) and the corresponding effect size φ. Single p-values show the results of Fischer method calculations, applicable only when between-group differences in response frequency were directional consistent. Non available (n.a.) comparisons reflect that the respective motor response did not occur in neither group.

Table C1.

Repeated measures (RM) ANOVA for the decision time in all right- and left-handed attacks.

Offense action	**RM ANOVA**	**Right-handed attacks**	**Left-handed attacks**
Breakthrough			
	Main effect	**$F(6, 90) = 4.42$, $p < .001$**	**$F(6, 84) = 27.48$, $p < .001$**
	Between-group	$F(1, 15) = 0.32$, $p = .581$	$F(1, 14) = 1.39$, $p = .257$

	Group~occlusion	*F*(6, 90) = 0.35, *p* = .910	*F*(6, 84) = 1.09, *p* = .374
Jump throw			
	Main effect	***F*(6, 78) = 10.34, *p* < .001**	***F*(6, 96) = 32.51, *p* < .001**
	Between-group	*F*(1, 13) = 3.07, *p* = .103	*F*(1, 16) = 0.01, *p* = .945
	Group~occlusion	*F*(6, 78) = 0.68, *p* < .666	*F*(6, 96) = 1.57, *p* < .165
Standing throw			
	Main effect	***F*(6, 96) = 9.52, *p* < .001**	***F*(6, 120) = 18.67, *p* < .001**
	Between-group	*F*(1, 16) = 0.00, *p* = .975	*F*(1, 20) = 2.60, *p* = .123
	Group~occlusion	***F*(6, 96) = 2.33, *p* < .038**	*F*(6, 120) = 0.86, *p* < .523
Pass			
	Main effect	***F*(6, 96) = 6.51, *p* < .001**	***F*(6, 114) = 17.29, *p* < .001**
	Between-group	*F*(1, 16) = 7.47, *p* = .400	*F*(1, 19) = 0.09, *p* = .771
	Group~occlusion	*F*(6, 96) = 1.46, *p* < .201	*F*(6, 114) = 1.10, *p* < .369

Note. Calculations were made to assess the main effect of the occlusion condition, between-group effects for level, and the group~occlusion interactions across occlusion points.

List of Publications and Presentations

Publications

Hinz, M., Lehmann, N., Musculus, L. (2022). Elite Players Invest Additional Time For Making Better Embodied Choices. [Currently under review at Frontiers in Psychology].

Hinz, M., Lehmann, N., Melcher, K., Aye, N., Tolentino-Castro, W.-J., Wagner, H & Taubert, M. (2022). Differences in Decision-Making Behavior between Elite and Amateur Team-Handball Players in a Near-Game Test Situation. *Frontiers in Psychology*, 13:854208. https://doi.org10.3389/fpsyg.2022.854208

Hinz, M., Lehmann, N., Melcher, K., Aye, N., Radić, V., Wagner, H., and Taubert, M. (2021). Reliability of Perceptual-Cognitive Skills in a Complex, Laboratory-Based Team-Sport Setting. *Applied Sciences*, 11, 5203. https://doi.org/10.3390/app11115203

Scientific Conference Presentations

Hinz, M. (2021). Differences in Decision-Making Behavior between Elite and Amateur Team-Handball Players in a Near-Game Test Situation. Presented at 6th European Handball Federation Scientific Conference.

Additional Publications and Presentations Related to Thesis

Wagner, H., Hinz, M., Fuchs, P., Bell W. J., & von Duvillard, S. P. (2022). Specific on-court performance in elite male adolescent team-handball players. *International Journal of Sports Physiology and Performance*. Advance online publication. https://doi.org/10.1123/ijspp.2021-0247

Wagner, H., Fuchs, P., & Hinz, M. (2021). Specific on-court performance in male adolescent team handball players. In: Book of Abstracts of the 26th Annual Congress of the European College of Sport Science (p.88).