Contextual cues and anticipation:
The effect of event history on anticipatory behavior in tennis

Dissertation for the acquisition of the academic degree
Doktorin der Philosophie (Dr. phil.)

Submitted to the Institute of Sports and Sport Science
of the University of Kassel

By Ricarda Stern

Day of oral defense: 24th May 2018

Reviewers: Prof. Dr. Norbert Hagemann
(Institute of Sports and Sport Science, University of Kassel)
Dr. Florian Loffing
(Institute of Sport Science, Carl von Ossietzky University of Oldenburg)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

"When you play a player 10 or 20 times, you also know the chances of where the balls are going to go. It's not so much anticipation anymore. Eventually, it's maybe more percentages and you start to learn those as well as time goes by."

- Roger Federer (2011)

Recognized as one of the greatest tennis players of all time by analysts, fans, as well as his opponents, 35 year old Swiss professional tennis player, Roger Federer, is often admired for his "smooth" style of play and more notably, his ability to read the game. "[…] his anticipation, I guess, that is the one thing that we all admire", says former professional player Rod Laver (Stauffler, 2010, p. 239), who himself is regarded as one of the greatest in history. In tennis, where we find extremely high ball velocities of up to 200 km/h for serves and around 110 km/h for groundstrokes (Deutscher Tennis Bund, 2004), the ability to read the opponent, or in other words, to anticipate their action intentions, is crucial to successful performance.

A large body of research has focused on identifying the perceptual features that enable athletes to predict future events, such as the opponents' action intentions, which can thereby facilitate quick, task-related and successful reactions in time-constrained situations. Particularly, a frequently reported finding is that skilled athletes are able to make earlier and more accurate predictions regarding their opponents' action intentions when compared to their novice counterparts (for a meta-analysis, see D. T. Y. Mann, Williams, Ward, & Janelle, 2007). It has been suggested that this improved predictive ability promotes a primary reliance on information from the movements of their opponents, oftentimes referred to as postural, kinematic or advance cues. For example, tennis players observe the swing of the arm and the racket of their opponents in order to predict the direction of subsequent strokes (Goulet, Bard, & Fleury, 1989; A.M. Williams, Ward, Knowles, & Smeeton, 2002). While the perception and usage of kinematic cues has been extensively studied in past research when examining the anticipatory process of an opponent's action intentions, another source of pertinent information seems to have been vastly neglected. During their development, expert athletes accumulate domain-specific knowledge about situational probabilities, or in Federer's words

(2011): “percentages”. This means, in specific situations, experts have a prior-assumption “that one action is more likely to occur than another one” (Cañal-Bruland & Schmidt, 2009, p. 236). In order to further analyze this phenomenon, a variety of information can be used to determine if an athlete considers one action more likely to occur than another, or as Federer alludes to in the above quote, an opponent’s individual action preferences. Thus, subjective probabilities can be deduced from different non-movement related cues, referred to as contextual cues. In past years, there has been an increasing interest in examining the role of discrete contextual information sources, such as an opponent’s position on the field (Loffing & Hagemann, 2014a), their action preferences (D. L. Mann, Schaefers, & Cañal-Bruland, 2014; Navia, van der Kamp, & Ruiz, 2013), strategic game information, such as game score (Paull & Glencross, 1997), the level of tactical initiative (Crognier & Féry, 2005) and further relevant cues outside the opponent’s movements. Given this plethora of information surrounding the role of discrete contextual information sources a recent call has been made to encourage researchers to work towards a better understanding of this issue (see Cañal-Bruland & Mann, 2015). Amongst other factors, the outcome of previous events and the pattern of event sequences were assumed to influence expectations. This assumption originated from research conducted on judgement and decision making, suggesting that humans actively search for and rely on sequential patterns to guide their future expectations and/or behavior (cf. Loffing, Stern, & Hagemann, 2015; for a review, see Oskarsson, Van Boven, McClelland, & Hastie, 2009). Initial research findings indicate that sequences of event outcomes may depict a salient contextual cue in the anticipation process (e.g., Gray, 2002; Misirlisoy & Haggard, 2014), even in the presence of an opponent’s movement kinematics (Loffing et al., 2015). However, these findings are, to date, rather exclusive experimental studies examining the direct influence of previous event sequences on anticipation in time-constrained sports tasks and further understanding is warranted.

The aim of this dissertation is two-fold. First, it seeks to provide a comprehensive review of the existing literature pertaining to the role of contextual cues in the anticipation process. Furthermore, an attempt to structure and systemize associated research findings is conducted in order to develop a model that captures the temporal availability and interaction of contextual and kinematic cues in the anticipation process as well as the possible determinants that act upon this process. The second purpose of this thesis is to empirically examine the role of event sequences and patterns in event sequences on visual anticipation of action outcomes in sports, particularly, in tennis. As mentioned before, initial research findings indicate that patterns in sequences of event outcomes may lead to an expectation bias that influences anticipatory behavior even in the presence of an opponent's kinematics (Loffing et al., 2015). Three empirical studies have assisted in further addressing this issue. The first research study comprises an extensive analysis of real tennis match data and examines possible relations between preceding serves or patterns in sequences of preceding serves and action outcomes in subsequent serves. The purpose of this study is to gain primary insight on the possible dependencies in the server's choices of stroke directions as well as any potentially associated probabilities of success that may be suggestive of a pattern-induced expectation bias of the return players. Based on this, Study 2 experimentally examines the effect of patterns in a server's choices of serve directions on expectations towards a subsequent serve. For this purpose, a laboratory-based study design was developed which allowed manipulating the outcomes of previous serves and isolating the influence of kinematic information. In Study 3, a similar research design is chosen to investigate the role of an opponent's choice of previous shot directions on the expectations of a player during rallies. Study 2 and 3 both looked at determining whether sequences of event outcomes depicted a salient contextual cue in the anticipation process in the presence of kinematic cues and if domain-specific experience affected the weighting of such information. The overall purpose of this dissertation is to explore the role of a priori contextual information as it pertains to our general understanding of the anticipation process and to gain a more specified understanding of the influence of previous event outcomes on anticipatory behavior.

Following the introduction, the theoretical portion of this dissertation is divided into two main sections. Chapter 2 provides a review of the extant literature on anticipation in sports with a particular focus on the role of contextual cues. Herein, theoretical concepts are introduced and a critical appraisal of the existing research in this field is offered in order to underpin the research studies conducted within this dissertation. Chapter 3 reviews the existing literature pertaining to the perception and judgement of event sequences and the theoretical concepts behind them. Following this, the aim of

Chapter 4 is to bring together the two components of the theoretical background of this dissertation – anticipation in sports and event sequences. Here, empirical evidence on the effect of previous event sequences regarding visual anticipation of action outcomes in sport is discussed in order to form a coherent theoretical framework for the research questions, which are introduced in Chapter 5. Chapters 6 through 8 focus on the three studies that comprise the research program. They build on one another and examine specific hypotheses in order to contribute to the existing body of knowledge pertaining to the effect of event history on anticipatory behavior (in tennis). Chapter 6 will begin by examining the existence of specific patterns in event outcomes using real match data and will conclude with an attempt at detecting first indications of dependencies in event sequences. In Chapter 7, a study is presented that examines susceptibility to patterns in previous event sequences (here: serve behavior) through analysis of a tennis task that requires rapid decisions to be made regarding the intentions of an opponent. After finding first evidence of a pattern-induced expectation bias in the study on serve-sequences, chapter 8 places a focus on the effect of patterns in opponent's stroke directions on anticipatory behavior during tennis rallies, using a similar perceptual judgement task. Chapter 9 contains a general discussion summarizing the key findings presented in the three studies analyzed and will attempt to draw upon associations of them with existing literature in the field. Furthermore, this chapter will delineate the practical implications arising from the research, address possible limitations inherent in the respective study methodologies, as well as highlight the potential for future directions and investigations in the field. Finally, a conclusion is drawn in Chapter 10.

2 ANTICIPATION IN SPORTS

A well kicked soccer ball with a speed of 100km/h travels from the penalty mark to the goal in about 400m/s. This is not a lot a lot of time for the goalkeeper to react and defend the 7.32 meters wide and 2.44 meters high soccer goal. Rightly, saving a penalty kick has been named as one of the “10 hardest things to do in sports” (USAToday, 2005). Next to hitting a baseball, which also requires exceptional reactions skills, it is not surprising that we find the act of returning a tennis serve in this list as well. The actual (unofficial) speed record for a tennis serve is held by the Australian Samuel Groth, who was able to accelerate the ball up to 263 km/h at a tournament in Korea in May 2012. Albeit these velocities are not consistently reached in professional tennis, the average speed for first service in tennis still lies at about 190 km/h (Cross & Pollard, 2009). Given an estimated distance between the server and the returning player of 27 m, and by neglecting the inherent frictional forces involved, the ball has the potential to reach the receiver after a time of 500 ms. If the receiving player were to wait until they seen the ball flight to decide in which direction to move to successfully return the ball, it would give them merely 500 ms to react to the direction of the ball, to move their body to the position needed to execute the return stroke and then to complete the stroke itself. Keeping in mind that it already takes at least 300 ms to decide which of the two options has occurred, (e.g., if the ball is played down-the-line or cross-court) there is clearly insufficient time in which to execute the return stroke effectively (Abernethy & Wollstein, 1989). Despite these minimal reaction times, it has been noted that even in such stressful, high-speed, competitive conditions, expert athletes seem to have all time in the world (Bartlett, 1947). Therefore, it is evident that anticipation must be an integral part of successful performance (cf. Abernethy & Wollstein, 1989).

Due to the high ball velocities reached in various dynamic sports, the duration of the ball flight has the potential to be shorter than the sum of the player’s response and reaction time. This makes it necessary to quickly perceive the intentions of the opponent and initiate an adequate response action before the opponent executes the shot, the kick or the throw. Therefore, skilled athletes must rely on earlier information than provided by ball flight to determine the direction and force of an opponent’s action. In other words, a predictive judgment has to be made based only on information available in early stages of the opponent's movement, such as before racket-ball-contact, foot-ball-contact or before the ball is released from the hand, e.g. in handball throws. Contextual information (which is available before a stroke, throw or kick even commences) related to the probability of the opponent executing a specific type of action and pertinent postural information could be both valuable and necessary sources of information available to improve anticipation (Abernethy & Wollstein, 1989; Murphy et al., 2016).

It is not surprising that at an elite level, it is not so much the physiological and anthropometrical attributes of an athlete that determine success, but rather the technical and psychological attributes that make the difference. Such attributes include resiliency under pressure, mental toughness, strategic thinking, and above all, 'game intelligence', which reflects an athletes' ability to effectively anticipate an action and make decisions (cf. A.M. Williams & Ford, 2013). Rod Laver, Australian former tennis player widely regarded as one of the greatest in history, explained the dominance of Roger Federer as follows: "Roger's got too many shots, too much talent in one body. It's hardly fair that one person can do all this – his backhands, his forehands, volleys, serving, his court position…the way he moves around the court, you feel like he's barely touching ground and that's the sign for a great champion. And his anticipation, I guess, that is the one thing that we all admire" (Stauffler, 2010, p. 239). So while all top-level players have acquired a comparable level of fitness, technique and tactical knowledge, it is Federer's perceptual-cognitive skill and ability which sets him apart from the competition. As highlighted earlier, the extreme time constraints evident in tennis and other fast ball sports, coupled with the fact that an opponent may try to feint and hide their intentions (Jackson, Warren, & Abernethy, 2006), make anticipatory skills crucial to successful performance.

In fast ball sports, in which the uncertainty and the spatiotemporal constraints on the performance are significant, the ability to "read" the opponents intentions is crucial to performance. The ability to foresee future event outcomes based on previous information, e.g., the trajectory of the ball based on an opposing player's movements, is referred to as "anticipation". However, this term is not only applied in the context of sports but used widely in a variety of settings. Oftentimes, these contexts can partially implicate different meanings of the term anticipation, which can result in some confusion as similar terminology is often used to describe the full range of these scenarios. Therefore, the following section will attempt to delineate the difference between anticipation and other related terms such as prediction and expectation. In addition, the mechanisms underlying decision making and anticipation will be succinctly summarized.

2.1 Anticipation – a highly multidisciplinary theme

The term anticipation has its origin in the mid-16th century and comes from the Latin word ‘anticipat’ - acted in advance (‘ante’ meaning before, and ‘capere’ meaning take) of the senses “to see what might happen in the future and take action to prepare for it” (Anticipation, 2005). On the one hand, rather colloquial, the term anticipation is also used to describe an emotion connatural to enthusiasm. It refers to a feeling of excitement and sometimes anxiety about an event that will happen in the near future. On the other hand, anticipation is an expectation or a mental presumption of a future event. From a psychological point of view, this definition can be extended to include on what basis anticipation is taking place. The mental presumption towards a future event is based on experiences and current perception (Schnabel & Thiess, 1993). The definition from Schnabel and Thiess (1993) points to the relevance of underlying cognitive processes (experiences stored in memory and current perception) for anticipation. When referring to a sport-psychology context, the nature of the future event has to be specified. With regard to sport situations, Munzert (2003) defines anticipation as the skill of foreseeing a future event, the effect of an event or dynamically changing environmental conditions. A future event in this context could be the direction and force of an opponent’s stroke, kick or throw, for example. Gatev (1968) describes anticipation as “a mechanism which begins to function whenever it is necessary to react in a certain way at a precise moment which is shorter than the latent period of reaction” (p. 236). In particular, Gatev’s definition seems to capture the temporal constraints put on an athlete in dynamic sport situations.

From a slightly different perspective, in relation to the action theory, anticipation includes everything prior to an event or an action, which refers to this event or the action and the goals, means and outcomes associated with it (Widmaier, 1987). In matters of predictive processing, further terms like expectation, prediction, prospection or preparation have been used. Bubic, von Cramon, and Schubotz (2010) delivered a systematic summary of the basic terms that describe different aspects of a general orientation towards the future (Fig. 1).

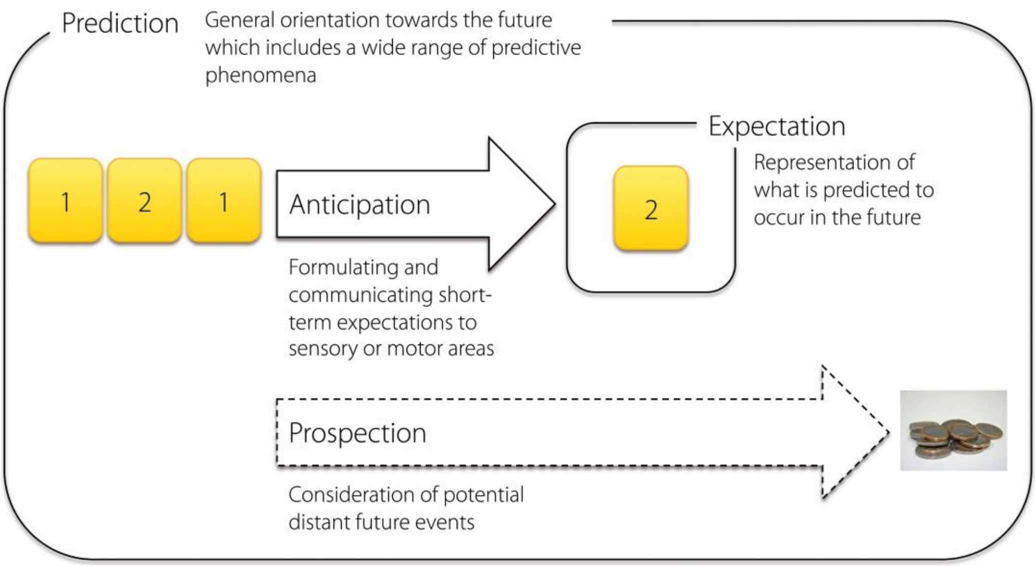


Fig. 1 Basic terms that describe different aspects of a general orientation towards the future.

According to Bubic et al. (2010), when we are confronted with a sequence of regularly alternating numbers, in this case “1” and “2”, we shortly start expecting that a number “2” should occur after the number “1”. This process results in a specific anticipatory activation of the sensory as well as motor cortex. The representation of what is predicted to occur in the future (in this case the number “2”) can be named expectation. This type of a process occurs on a short timescale. In turn, the consideration of potential distant future events, which do not necessarily lead to specific sensory or motor preactivations, can be termed prospection. While all these terms describe somewhat different phenomena, Bubic et al. (2010) suggest that they may all be considered as specific aspects of a common directedness towards the future, summarized under the term prediction.

While often used in a similar manner, Pezzulo, Butz, and Castelfranchi (2008) argue that a clear distinction needs to be drawn between predictive and anticipatory systems. According to them, prediction is “a representation of a particular event” whereas anticipation is “a future-oriented action, decision, or behavior based on a (implicit or explicit) prediction" (p. 25). While predictions are generally based on prior knowledge, different sources of prior information, albeit not mutually exclusive, can be used. Such examples of prior information can include statistical regularities, analogy, inference, functional stance and intentional stance[1] (Pezzulo et al., 2008).

In order to fully grasp the concept of anticipation in sports, we must first define anticipation as it applies to this context. In accordance to Pezzulo et al. (2008), anticipation must not implicate an outward visible behavior or action, but the mere mental formulation of an expectation (cf. Bubic et al., 2010). With this in mind, Munzert's (2003) definition of anticipation reflects a more generalized understanding, as it refers to the skill of foreseeing a future event, an events effect, or dynamically changing environmental conditions - which should be taken as the basis for this work. At the same time, all facets of anticipation are of relevance to understanding the theoretical and empirical findings presented in this work. As in most of the literature from the field of sports, no clear differentiation between the terms anticipation and prediction is conducted, therefore the two terms will be used in a synonymous manner.

Anticipation plays a major role not only in dynamic sport situations but also in everyday life. Early behavioral experiments conducted by Wilhelm Wundt in the 19th century elucidated that perception time can be shortened by attention and expectations related to the upcoming stimulus (Bubic et al., 2010). Forming expectations leads to a faster recognition and interpretation of upcoming events by limiting the number of potential responses to such events (Bar, 2007). Resources are saved and the perceiver can prepare appropriate actions (Llinás, 2002). Hence, predictions can lead to an increase in accuracy, speed or maintenance of information processing (LaBerge, 1995). This puts forth the notion that anticipatory processes are essential in everyday cognition. The ability to anticipate future events is often regarded as one of the most important perceptual skills underlying visual perception and cognition (Braithwaite & Humphreys,

---

[1] When we assume a functional stance, we form predictions on the basis of the functionality of things in our environment, e.g. we would predict that a car without an engine will not move. However, a functional stance does not make sense for all objects in our environment, particularly if we think of human behavior. In turn, an intentional stance permits the prediction of others behavior. If we treat an agent as an intentional entity, we use a representation of the other's mind for predicting its behavior (Pezzulo et al., 2008). For example, if we know that someone likes soccer, we can predict that they will watch the television broadcast of the Champions League.

2003; Summerfield & Egner, 2009), linguistic processes (Kamide, 2008) and effective motor performance (A.M. Williams et al., 2002). For example, when driving, the ability to anticipate hazardous traffic situations can reduce the risk of an accident occurring (McKenna & Horswill, 1999; van der Hulst, Meijman, & Rothengatter, 1999). Obviously, such anticipatory processes are especially necessary in settings calling for online control (Strack, Kaufmann, Kehrer, Brandt, & Sturmer, 2013). Accordingly, anticipation is often associated with certain awareness. We have to monitor our surroundings at all times (for example in traffic or during social contacts), so we can foresee events and actions and act preventatively to avoid any potentially negative outcomes. “Prediction allows us to act, and not solely react to events occurring around us” (Bubic et al., 2010, p. 6). Kunde, Elsner, and Kiesel (2007) offer a strong statement: “acting without anticipating is impossible” (p. 76).

Anticipation is a highly multidisciplinary theme. Comprehensive research findings in psychology and neurobiology indicate the presence of several anticipatory mechanisms in the brain and highlight the crucial role that anticipation plays in cognitive functioning, such as vision, motor control, learning, motivational and emotional dynamics (Pezzulo, Hoffmann, & Falcone, 2007). According to Llinás (2002) “the capacity to predict the outcome of future events - critical to successful movement - is, most likely, the ultimate and most common of all global brain functions” (p. 21). Furthermore, Pezzulo et al. (2007) places anticipation “at the core of cognition” (p.68). The concept of anticipation or predictive processing, as a fundamental principle of brain function, justifies the notion of “the predictive brain” (Bubic et al., 2010).

The benefits of prediction or anticipation become particularly apparent when we focus on motor tasks and dynamic sport situations. Especially in fast ball sports where high ball-velocities lead to high spatio-temporal constraints making the anticipation of an opponent’s action intentions crucial to successful performance (see chapter 2.4). To deliver a comprehensive report of the theoretical background of this work, the physiological processes and mechanisms underlying anticipation and decision making will be shortly summarized in the following section.

2.2 Mechanisms underpinning anticipation and decision making

Fig. 2 (modified from A.M. Williams & Ford, 2013) illustrates the mechanisms, processes and skills underpinning visual anticipation and decision making as they pertain to the visual system, the brain or the motor apparatus, in matters of sport situations.

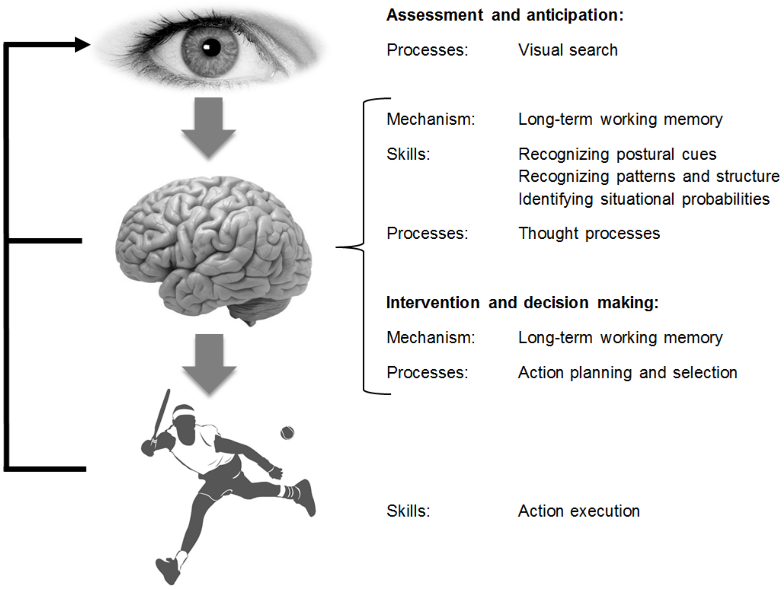


Fig. 2 The processes, mechanisms and skills underlying anticipation and decision making (modified from A.M. Williams & Ford, 2013).

The visual system is responsible for the pick-up and processing of visual information extracted from our environment. By comparison with memory, relevant information is extracted and interpreted. For example, an athlete will observe a certain behavior of an opponent and recognize aspects from past behavior, leading him to expect e.g., a specific shot direction. Based on this, he will decide on an appropriate reaction and initiate his response movement. The figure illustrates that with regard to the mechanisms of anticipation and decision making, processes of the visual system, the brain and the motor system have to be considered, as they all participate and interact to support visually guided behavior.

2.2.1 Visual perception

Visual information from our environment is the source of which we rely most upon when we act in our environment (Cutting, 1986; Lee, 1978). Therefore, visual perception plays a vital role in every-day life. Visual perception includes not only the pick-up but also the processing of visual information. We activate our memory to extract, recognize and interpret relevant visual features from the visual scene. For those who are limited in their ability to process visual stimuli (e.g., people who suffer from any kind of eye impairments or blindness), managing every-day life without some form of support can be difficult, especially in movement behavior, where visual perception plays a significant role. When we move through our environment, we monitor our surroundings in order to react to changes. For example, we walk through a crowded street without bumping into other people or tripping over steps. Nowadays, we often see people who experience the disadvantages of not visually monitoring their environment. For example, when using a smartphone, individuals might stumble, run into street lamps or similar objects, or even cause a traffic accident.

Due to the high spatio-temporal constraints placed upon performers during sport situations, the importance of vision to the athletes is self-evident[2]. Visual information from the opponent or the ball as they move within the environment is used to support goal-directed actions of an athlete. In interactive fast ball sports, athletes need to initiate their response-movement before the ball actually reaches them. Therefore, they have to estimate ball location in space (“where”) and time (“when”) based on the initial trajectory of ball flight. Due to high ball velocities, it is often not sufficient to rely on the initial trajectory but to move before a ball even leaves the hand, foot or racket. This means athletes have to use visual information from the opponents’ movements and form expectations based on this information. Therefore, the examination of the pick-up and use of visual information in sport situations, and in particular the visual search behavior is a main component of research when attempting to understand anticipation in sports (see chapter 2.4). For example, researches register the eye movements of athletes in sport situations to gain insight on what information from the visual display might be relevant to successfully predicting future event outcomes, such as shot direction.

While the eyes are the primary physiological component responsible for the interpretation of visual information, further processing of visual information, anticipation and decision making is carried out by the brain.

---

[2] Please note that athletes that suffer from visual impairments or blindness also reach top performances in ball-sports, as they have learned how to rely upon their other senses, which make them worthy of our full respect. However, for athletes without visual impairments it is unimaginable how one can overcome the high spatio-temporal constraints put on them during dynamic sport situations without full vision.

2.2.2 The role of the brain as a prediction device

"The purpose of brains is to produce future." (Paul Valery)

The term "predictive brain" constitutes the most essential concepts in cognitive neuroscience, highlighting the importance of foreseeing the future in fact prediction, anticipation, prospection and expectations, in various contexts (Bubic et al., 2010).

As prediction pertains to different types and levels of processes, it is difficult to identify common neural mechanisms which support such processing across all contexts. Generally speaking, predictive processing has been related to almost all brain regions and networks (Bubic et al., 2010). According to Bubic et al. (2010) there are different ways of conceptualizing and differentiating the roles of various brain regions in prediction. One approach, which depicts a very rough simplification, is to distinguish between the sources and sites involved in the process of prediction. Higher-level areas of the brain, such as the lateral, medial, and orbital sections of the prefrontal and premotor regions (sources), formulate expectations and have the potential to impose a bias. These expectations are communicated to lower-level processing centers of the brain, usually sensory areas (sites). However, further dimensions, e.g., the timescale of prediction, cognitive domain and context, may be crucial in determining the actual sources involved. In contrast to these, the predictive coding model represents a more holistic approach through which the brain is seen as a "Bayesian inference machine", continually integrating information about the environment and the body to predict future conditions.

In line with this approach, Cisek (2007) contrasts two conceptual taxonomies of neural processes in the context of visually guided behavior. A taxonomy implied by classical cognitive science, classifies brain functions as (serial) processes in the perceptual, cognitive or action systems. The second, alternative taxonomy classifies brain functions as processes aiding either action specification or selection in a simultaneous manner, continuing even through overt performance of movements. That is, sensory information from the environment is constantly used to specify possible actions, while additional information is collected to aid in understanding the options that are available and then making a decision based on those options, at a given moment (Cisek, 2007). This so called affordance competition hypothesis may be used to interpret neural data from the primate cerebral cortex during visually guided behavior. Figure 3 illustrates the possible neural substrates of the affordance competition hypothesis in the context of visually guided behavior (Cisek, 2007). The filled dark arrows represent processes of action specification, while double line arrows represent processes of action selection. Action specification begins in the visual cortex and proceeds through the parietal lobe, transforming visual information into representations of potential actions. Three neutral populations (representing the encoding of potential visual target, the encoding of potential actions and activity in premotor regions) are represented as square segments, showing the spatial distribution of neural activity, with peaks corresponding to the lightest regions. In the fronto-parietal cortex, potential actions compete for further processing biased by input from the basal ganglia and prefrontal cortical regions. Due to reciprocal connectivity, the competition is reflected in a large area of the cerebral cortex. When a final selection is made, execution is initiated and causes both external environmental feedback (dashed black arrow) and internal predictive feedback through the cerebellum.

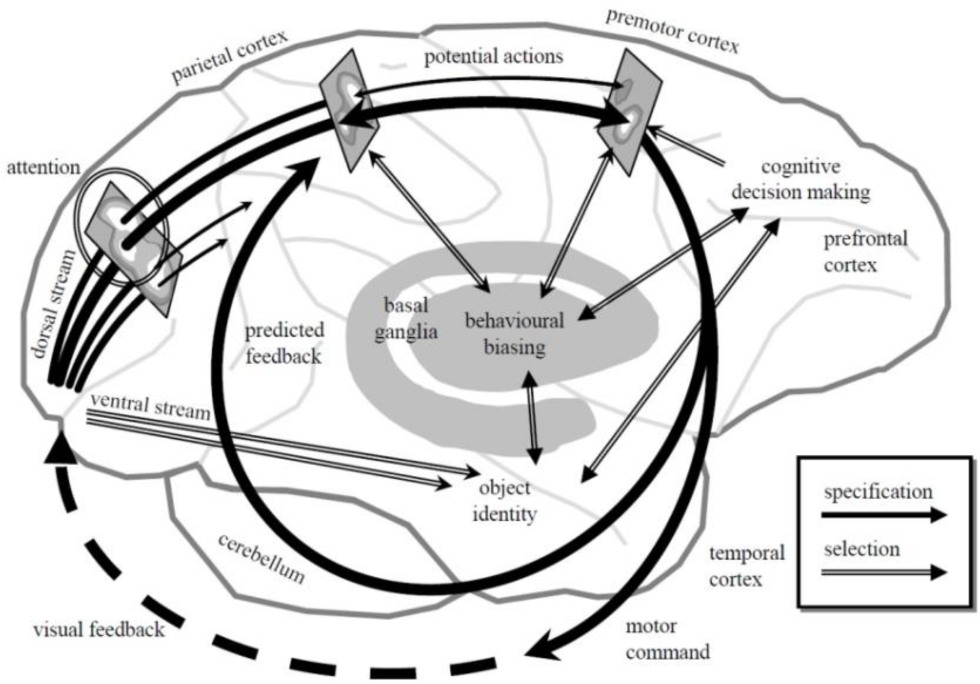


Fig. 3 Possible neural substrates of the affordance competition hypothesis in the context of visually guided behavior. According to the author, this alternative taxonomy is better suited to interpret neural activity in many brain regions, which is supported by neurophysiological data arguing against a serial viewpoint. Furthermore, it facilitates understanding of how cognitive abilities enable organisms to interact with their environment in adaptive ways (Cisek, 2007).

Currently, minimal scientific evidence exists regarding the neurophysiological responses of the brain during sport situations. However, a recently growing body of literature reflects the increasing interest in examining brain areas involved in anticipation and decision making in sport (Balser, Lorey, Pilgramm, Naumann, et al., 2014; Balser, Lorey, Pilgramm, Stark, et al., 2014; Wright & Jackson, 2006). For example, Wright and Jackson (2006) used functional magnetic resonance imaging (fMRI) to identify the brain regions concerned with perceptual skills in tennis. In this case, players showed activation of the parietal and frontal cortex, which pertain to the mirror-neuron system, as well as in the middle temporal visual area and superior temporal sulcus, namely the visual attention system. In a later study they showed that activation in these areas was stronger in expert players, as compared to those competing at a novice level (Wright, Bishop, Jackson, & Abernethy, 2011). This possibly indicates structural and physiological changes in the brain caused through previous experience (Yarrow, Brown, & Krakauer, 2009). Correspondingly, Balser, Lorey, Pilgramm, Stark, et al. (2014) detected stronger neural activation for expert tennis players compared to novices during a video-anticipation task. Particularly, the areas of stronger activation were found in of the action observation network (AON), which predominately included the superior parietal lobe, the intraparietal sulcus, the inferior frontal gyrus, and the cerebellum. Furthermore, they suggest that the stronger activation reflects the use of more finely-tuned motor representations, which experts have acquired and improved during years of training. Hence, the neural processing of different anticipation tasks depends on the expertise level. Following the results of a related study, Balser, Lorey, Pilgramm, Naumann, et al. (2014) suggested that the superior parietal lobe (SPL) and the cerebellum are the predominant brain sites involved in fast motor predictions. While the SPL reflects the processing of domain-specific contextual information (e.g., positioning, surrounding, using a racket or not to hit the ball), the cerebellum reflects the usage of a predictive internal model to solve the anticipation task.

To further explore the brain-related mechanisms underpinning anticipation and decision making, more research is needed in the area of neuroscience.

2.2.3 The role of memory

Memory is seen as the mechanism within the brain, which underlies anticipatory information processing and decision making (e.g., A.M. Williams & Ford, 2013; Yarrow et al., 2009). Roughly speaking, memory enables organisms to benefit from their past experiences. In other words, our stored memories and experiences from past situations aid in forming our decisions and expectations of future event outcomes. Therefore, having the ability to retrieve such information from our memory in a quick and efficient manner is crucial to successful interaction in our environment.

It is well documented that two main memory stores exist, of which are termed short-term and long-term memory (Herriot, 2013). They are assumed to differ in capacity, type of coding and in the way items are lost. While short-term memory has a limited capacity, the store in long-term memory is virtually unlimited. Additionally, short-term memory (STM) is assumed to favor a coding system that is defined by an item's physical or phonological characteristics, whereas coding in long-term memory (LTM) depends on the meaning of the item. Items are lost or forgotten from the short-term store if they are overloading it, while items are lost from the long-term store if they are interfered with by other material (Herriot, 2013). Cognitive psychologists have shown that expert performance in anticipation and decision making cannot be sufficiently explained by the classic-information-processing conception of memory involving these two stores (e.g., Ericsson & Kintsch, 1995). Ericsson and Kintsch (1995) proposed a theoretical framework of a working memory based on storage in long-term memory, of which they referred to as long-term working memory (LTWM). Following their approach, the limitations of STM, especially its restricted capacity, are avoided by obtaining the ability to rapidly and reliably encode and retrieve information into LTM. This LTM contains domain-specific information which can be efficiently accessed through retrieval cues kept in STM. This way it also overcomes limitations of the classic LTM, which is less reliable and provides a slower encoding and retrieval process (A.M. Williams & Ford, 2013). Ericsson and Kintsch (1995) support their theoretical claims with evidence on memory in text comprehension and expert performance, e.g., in mental calculation, medical diagnosis, and chess. For skilled performance in sports, this means that athletes encounter information during practice or competition and are able to encode and store this information in LTM. This information is linked to a retrieval cue in STM. Correspondingly, when a similar situation is subsequently encountered, the performer can rapidly access the associated information stored in LTM through these retrieval cues (cf. Murphy et al., 2016). During practice and competitions, a tennis player will face various events and situations, e.g., a forehand cross-court rally with a stroke that ends up shorter than intended around the service line, encouraging the opponent to hit an attacking forehand down the line. At the same time, the performer is asked to respond to this event, e.g., to anticipate the direction and depth of the opponent's stroke and try to return the ball. This gives them the opportunity to encode information from these situations, associate this encoded information with a retrieval cue, and store the information in LTM. Therefore, when the player encounters a similar situation in a subsequent competition (e.g., a forehand cross-court rally with a stroke that ends up shorter than intended around the service line), the presented information is associated with a retrieval cue, allowing for the rapid retrieval of relevant information about that situation and potentially, the previous outcomes of such a situation (the opponent hitting an attacking forehand down the line) from LTM (cf. Murphy et al., 2016). Less-skilled athletes lack the experience and consequently, such advanced memory representations. Evidence in favor of the LTWM theory (Ericsson & Kintsch, 1995) in domain-specific anticipation tasks has been provided by several researchers (e.g., North, Ward, Ericsson, & Williams, 2011; Roca, Ford, McRobert, & Williams, 2011), who attribute differences in performance between skill groups to more advanced domain-specific memory representations.

Given the information presented at the beginning of chapter two, anticipation is necessary in everyday situations (e.g., in traffic) as well as in dynamic sport situations. With regards to the initiation and execution of a response movement, the underlying physiological mechanisms and processes of anticipation arise from the interaction of the visual system, the brain (memory), as well as the motor system. In various sports where high ball speeds are reached, it is common for athletes to face high spatio-temporal constraints when asked to execute an adequate response, e.g., when a goalkeeper has to save a penalty or when a tennis player has to return a serve. The significance of anticipation in dynamic sport situations was integrated in different models of tactical action in play. The selected models proposed in this context will be summarized in the following section. The adjacent chapter will then focus on anticipation in time-constrained sport situations and in particular, on the information sources athletes rely on to successfully anticipate their opponents' action intentions.

2.3 Anticipation in selected models of tactical action in play

The significance and necessity of anticipation in dynamic sport situations is integrated in different models of tactical action in play, which originated almost 50 years ago. In one of the first models of individual tactic, Mahlo (1965, 1969) identified three consecutive and connected components of tactical action (Fig. 4): (1) the perception and analysis of game play, (2) the mental solution to the problem and (3) the motor skill solution to the problem. In the first two phases, memory is accessed in terms of the knowledge surrounding the likelihood of evolution of the setting. This strongly reminds us of the anticipation process, although the term 'anticipation' is not explicitly mentioned in this model. The result of phase three, the motor-skill solution of the problem, is evaluated through a repertory of answers at disposal and used to modify contents of memory.

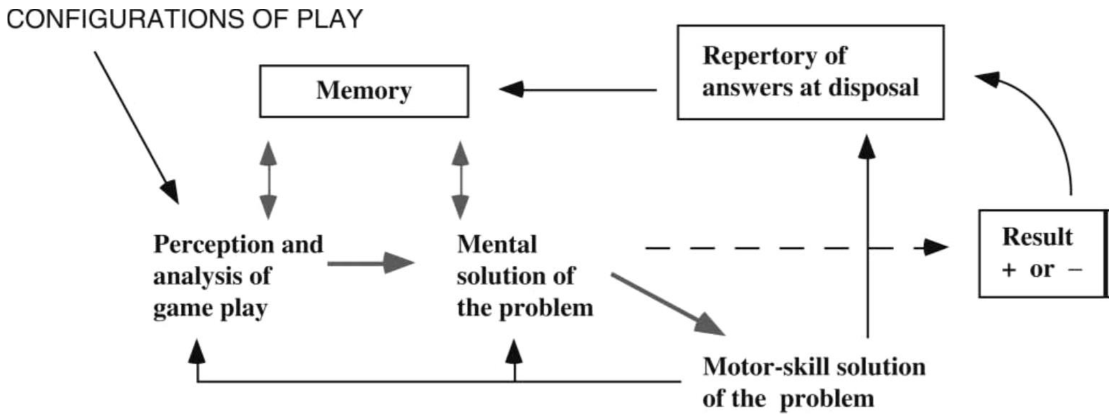


Fig. 4 The game play phases according to Mahlo (1969).

Regarding his model, Mahlo (1965) explicitly points out that due to ever-changing situations, perception and mental solution are not carried out successively but rather in a contemporaneous manner. For example, consider a soccer goalkeeper's task to prevent a penalty shooter from scoring a goal. While perceiving the behavior of the shooter, their run-up, viewing direction, posture and movements, the goalkeeper may revert back to his/her memory where information affecting the likely outcome of the kick is stored, e.g., the shooter's preferences or the likelihood of a certain shot-direction in combination with the observed run-up angle. The resulting mental solution of the problem (deciding in which direction to dive) is followed by the motor-skill solution. Subsequently, depending on the result of the solution, (whether the goalkeeper decides on the right direction and if the penalty is saved) contents of memory are potentially modified. For example, if based on the run-up angle and the previously observed preferences of the shooter, the goalkeeper decides to dive to the right, but instead the shooter unexpectedly uses the outside of the foot and kicks to the left, the goalkeeper will now add this experience to his memory and have the opportunity to refer to it in an ensuing penalty situation.

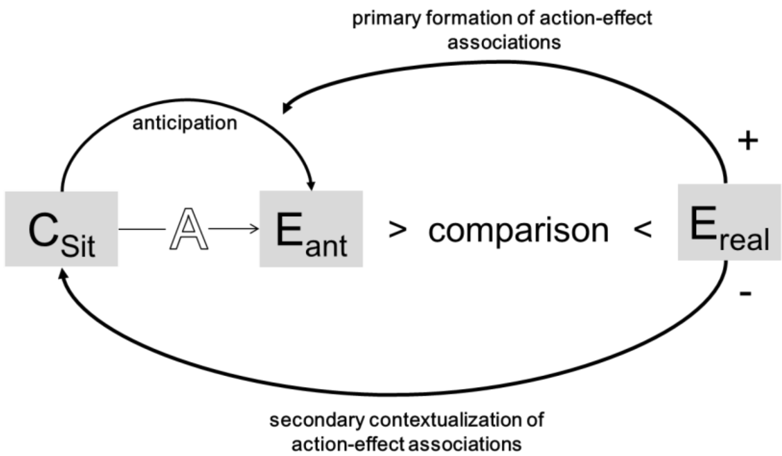


Fig. 5 The Anticipatory Behavioral Control framework (modified from Hoffmann, 1993, p. 44).

According to Büsch, Schorer, and Raab (2016), subsequent models of tactical action following Mahlo's model can be regarded as an advancement of this basic framework, which highlights either a particular aspect or a specific interdependency. In contrast to phase models like the one from Mahlo (1965), process models differentiate between explicit top-down- and implicit bottom-up-processes of tactical action. In the Anticipatory Behavioral Control (ABC) framework by Hoffmann (1993, Fig. 5), learning mechanisms and anticipatory behavioral control are linked. Under specific situational conditions (C_{sit}) all voluntary acts (A) involve corresponding effect anticipations (E_{ant}). The real effects (E_{real}) are compared to the anticipated effects. If there is a sufficient coincidence between the desired outcome and the actual outcome, a link between the action and the effect is formed, or an already existing link is strengthened or relieved (primary formation of action-effect associations). Furthermore, the situational contexts become integrated into action-effect representations (conditionalization of action-effect associations) (cf. Hoffmann, 2010).

In SMART-ER (Situation Model of Anticipated Response-consequences of Tactical decisions – Extendend and Revised), a more recently published model, concrete predictions regarding the weighting of top-down- and bottom-up-processes of tactical actions are described through personal and situational characteristics (Raab, 2015). Top-down processes are characterized by a high level of cognitive control with respect to sensory processing, while bottom-up processes are characterized by an absence of cognitive control and use sensory information more directly. In the above mentioned penalty example, cognitive control could use the knowledge about the shooter's preference to shoot to the right of the goal, while information like the postural orientation of the shooter is used in a more direct fashion (bottom-up). Integrated into the model and describing an extension of the original SMART (Raab, 2007), the weighting of top-down and bottom-up processes is determined by the complexity of a situation, which can be manifested based on the number of options present, the visual information available, and the speed at which a decision has to be made (Raab, 2015).

Through analysis of these three models, and others which have not been discussed herein, it is evident that the structured breakdown of perception, decision making and action execution is a commonality which exists amongst them. While these processes are interdependent in nature, they still have the ability to function in a continuous manner (cf. Büsch et al., 2016). Without further describing these and other models of tactical action in sports in detail, it is clear that anticipation is an integral part in each one. Particularly in time-constrained sport situations, the ability to foresee an opponent's action intentions can be crucial to successful performance, as will be clarified in the next chapter.

2.4 Anticipating opponent's action intentions

As mentioned in the previous sections, high ball velocities reached in dynamic sports, such as soccer, hockey, baseball, handball or tennis, make it necessary for an athlete to quickly perceive the intentions of the opponent and initiate an adequate response action. Tab. 1 outlines a number of examples of varying ball speeds, their associated sport activity, and the resultant time available for the receiver to react.

Tab. 1 *The time available (sec) depending on various ball speeds in some typical sport situations. (Please note that for the calculation of time distances were estimated and friction force was neglected). The listed records were published by Riedel (2013).*

Sport activity	(Approx.) Distance	Ball speed (km/h)		Time available (sec)
Tennis serve	27 m	**Record**	**263 km/h**	**0.37**
			180 km/h	0.54
			120 km/h	0.81
Soccer Penalty	11 m	**Record**	**212 km/h**[3]	**0.18**
			100 km/h	0.39
			80 km/h	0.50
Handball Penalty	7 m	**Record**	**131 km/h**	**0.19**
			100 km/h	0.25
			80 km/h	0.32
Baseball pitch	18 m	**Record**	**160 km/h**	**0.41**
			120 km/h	0.54
			80 km/h	0.81

Keeping in mind that the initiation of an aligned action follows the visual perception of a stimulus with a 200 ms delay (e.g., Hyman, 1953), the times presented in the table illustrate that athletes have to make predictive judgments based on information available in early stages of the opponent's movement. Even though experts are assumed to have acquired a faster and more efficient perception-action coupling, which reduces their visuo-motor delays (e.g., Le Runigo, Benguigui, & Bardy, 2010), high ball velocities still force them to initiate their response action before the opponent's racket-ball-contact, foot-ball-contact or before the ball is released from the hand, e.g., in handball.

The question of how elite athletes deal with the challenging demands of fast ball sports is of great interest among sport scientists and researchers in motor behavior, especially those that aim to help athletes reach peak performance in their associated disciplines. Sport scientists are particularly interested in identifying the perceptual features that enable athletes to predict future events, such as the opponents' intentions, which can thereby facilitate quick, task-related and successful reactions in time-constrained situations. Previous research has steadily shown an expert advantage in anticipating an opponents' action outcome (for a meta-analysis, see D. T. Y. Mann et al., 2007) across various sport domains, including badminton (Abernethy & Russell, 1987a; Abernethy & Zawi, 2007; Hagemann & Strauss, 2006), baseball (Cañal-Bruland, Kreinbucher, & Oudejans, 2012), cricket (D. L. Mann, Abernethy, & Farrow, 2010; Mueller, Abernethy, & Farrow, 2006), soccer (Dicks, Davids, & Button, 2010; Neumaier, te Poel, &

[3] Please note that although designated as official, this record has been strongly contested and attributed to an incorrect measurement (e.g., Tolan, 2010).

Standtke, 1987; Savelsbergh, Williams, Van der Kamp, & Ward, 2002; Van der Kamp, 2006; A.M. Williams & Burwitz, 1993; A.M. Williams & Davids, 1998), squash (Abernethy, 1990a, 1990b; Abernethy, Gill, Parks, & Packer, 2001) and tennis (Farrow & Reid, 2012; Goulet et al., 1989; Neumaier, 1985; Shim, Carlton, Chow, & Chae, 2005; A.M. Williams et al., 2002).

To combat the pressure of time associated with fast interactive sports, athletes have to make predictions as to what their opponent is going to do next, whether that be a throw, a shot, or a hit. Among various sports, researchers agree that skilled athletes overcome spatio-temporal constraints through the effective use of advance cues. Such a priori information used for anticipation of opponents' action intentions can be derived from two different sources: (1) body language of an opposing player, often referred to as kinematic cues, and (2) context, which includes situational variables such as the opponent's strengths, weaknesses or preferences, climatic conditions and so on.

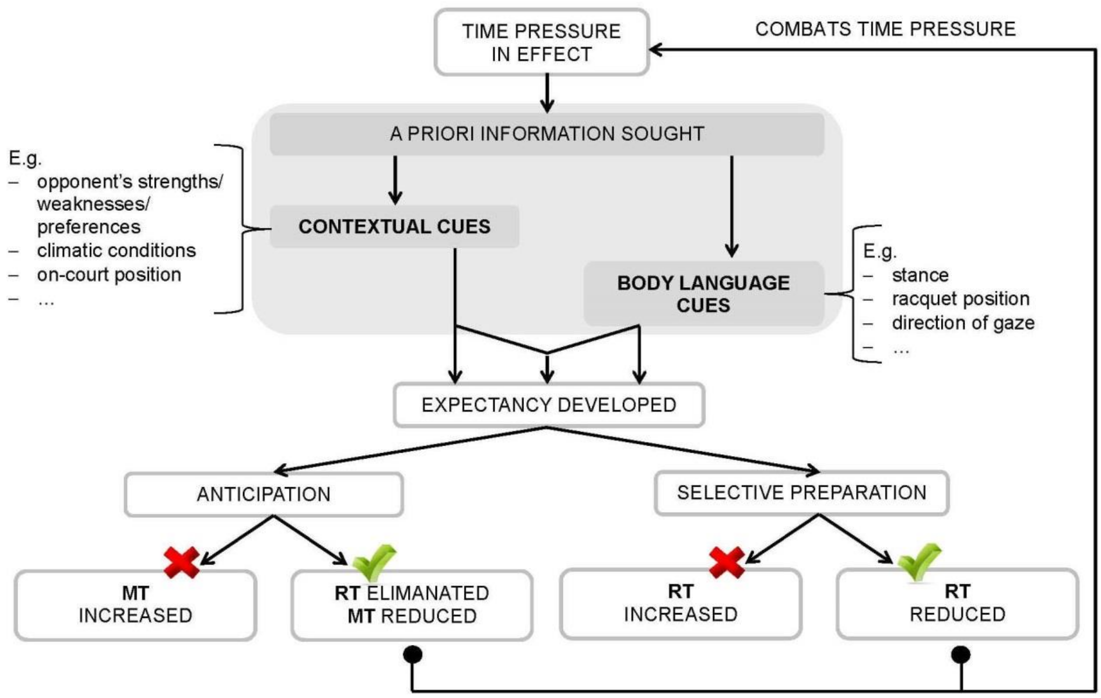


Fig. 6 The anticipation process in sports (modified from Buckolz et al., 1988).

In their schematic overview (Fig. 6), Buckolz, Prapavesis, and Fairs (1988) show the advantages to be gained through the effective use of a priori information. Here, contextual cues available earlier on may or may not be combined with later-perceived body language cues (depending e.g., on the time pressure; see chapter 2.3.3), of which dictate the level of expectancy developed. The authors differentiate two ways in which a time stressed individual can benefit from the use of a priori information, both of which function to overcome time pressure by reducing the time needed to complete an adequate reaction. The two ways include: (1) Selective preparation, which means one prepares for the most promising alternative. If this preparation turns out to be correct reaction time (RT) will be reduced; (2) Anticipation, which according to the authors means anticipatory mobilization, i.e., a player begins to move in the expected shot direction. If the fundamental prediction is correct, reaction time is eliminated and movement time is reduced. Buckolz et al. (1988) also illustrate the risk of incorrect predictions, in the form of increased time needed to perform a reaction movement.[4]

The breakdown of prior anticipation-relevant information sources into contextual and body language cues, made by Buckolz et al. (1988), was perceived among researchers at the time. However, until recently, the majority of research studies on anticipation in sports focused solely on the examination of kinematic cues rather than contextual ones, as they depict the most obvious information source when anticipating opponent's actions in sport situations. Central research findings pertaining to kinematic cue usage, as well as established research methods and paradigms, will be summarized in the following section. Subsequently, the role of contextual cues, which has gained the attention of researches particularly in recent years, will be extensively discussed as it represents a main component of the theoretical framework of this dissertation.

2.4.1 Kinematic cue usage

In various research works on expertise in sports, it was repeatedly shown that skilled athletes are able to pick up information from the orientation and movements of their opponents and use them effectively to anticipate situation outcomes (e.g., Abernethy & Zawi, 2007; Loffing & Hagemann, 2014b; Mueller et al., 2006; Savelsbergh et al., 2002). For example, expert tennis players are able to use information from the hitting movement of their opponent to forecast ball trajectory and velocity and to initiate an adequate reaction in sufficient time (Cañal-Bruland & Williams, 2010; A.M. Williams et al., 2002). Amongst others, the ability to anticipate an opponent's action intentions is

[4] Please note that the distinction drawn by Buckolz et al. (1988) between anticipation and selective preparation is somewhat an individual case and, as mentioned in chapter 2.1, a broader understanding of the term anticipation (comprehending the aspects of Buckolz and colleagues' "selective preparation") will be taken as a basis in this work.

typically examined with the help of the temporal occlusion technique. This paradigm describes a common approach to a differential analysis of perception and anticipation processes in sport situations. The basic idea behind the temporal occlusion technique is to occlude ones vision of an opposing player at a key moment of their movement. This is done in order to test if the observer is able to make the correct prediction of the future action of the opponent. In most cases, video material of particular sport situations, which show the opponent's action from a realistic perspective, form the basis of such temporal occlusion experiments. For example, an observer sees a video sequence from the perspective of a goalkeeper showing a player running towards him and executing a penalty kick. The observer's task is to anticipate shot-direction after the video is occluded, e.g., at foot-ball-contact (A.M. Williams & Burwitz, 1993). For more than 30 years the temporal occlusion method has been used successfully in a multitude of research studies and in various sport domains (e.g., Abernethy & Russell, 1987b; Farrow, Abernethy, & Jackson, 2005; Hagemann & Strauss, 2006; Jones & Miles, 1978; Mueller et al., 2006; A.M. Williams & Burwitz, 1993). Research studies using the temporal occlusion paradigm consistently show an expert advantage in the anticipation of event outcomes and opponent's intentions (Abernethy, Farrow, Gorman, & Mann, 2012). Skilled performers are able to make reliable predictions concerning direction and force of an opponent's throw, stroke or shot on the basis of early available information prior to foot-ball- or racket-ball-contact (e.g., Abernethy & Russell, 1987b; Farrow et al., 2005).

To apportion the anticipation process in a chronologically more differentiated manner the *progressive temporal occlusion paradigm* is used (Abernethy et al., 2012). It helps to draw more precise predications on how early in the event sequence or in the opponent's movement athletes can make reliable predictions on its outcome. Different experimental conditions are created through systematically manipulating the moment of occlusion. In each video sequence the same situation, and respectively the same movement, is presented to the observer with either more (at later points of occlusion) or less (at earlier points of occlusion) visual information (see Fig. 7). The chosen point of occlusion differs not only from study to study, but even between research studies which look at a particular task within a sport (e.g., anticipating serve directions in tennis, Farrow et al., 2005; Goulet et al., 1989). In general, two different strategies serve as orientation for choosing the various occlusion conditions (Loffing, Cañal-Bruland, & Hagemann, 2014): Either occlusion points are selected in temporal identical intervals based on a critical event in the movement, such as the foot-ball-contact or racket-ball-contact (Farrow et al., 2005); or occlusion points are determined by fundamental, key-points of a movement (e.g., point of ball release; Mueller & Abernethy, 2006) or movement phases (e.g., preparatory phase, execution phase, ritual phase; Goulet et al., 1989).

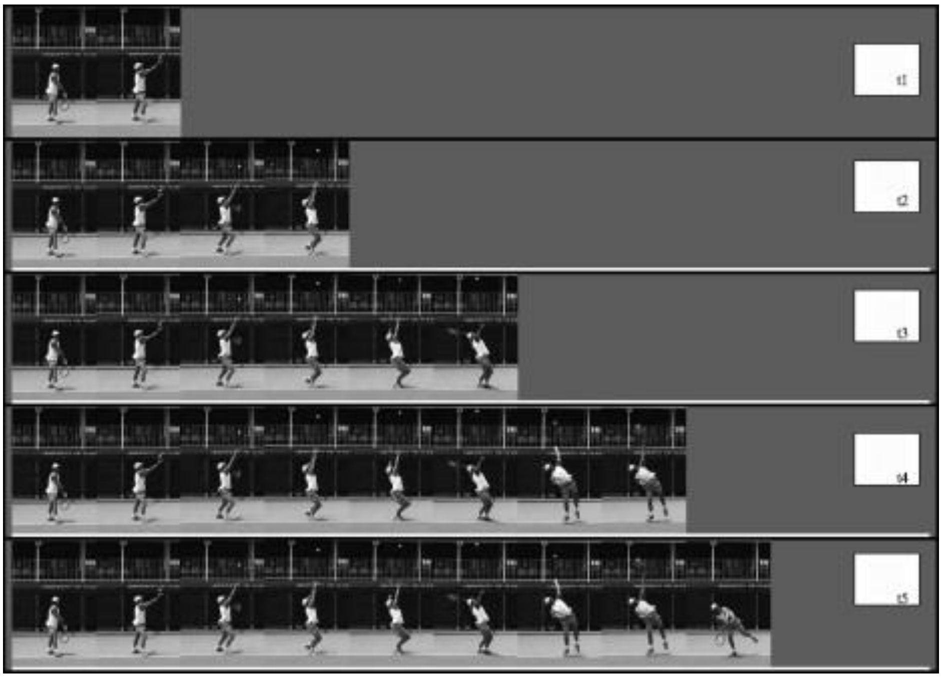


Fig. 7 Schematic illustration of five successive 300 ms occlusion conditions (Farrow & Abernethy, 2003, p. 1131).

A frequently reported research finding is that skilled athletes in a certain sport domain are superior at anticipating future events or opponent's intentions, when compared to less skilled performers (for a meta-analysis see D. T. Y. Mann et al., 2007). Not surprisingly, and irrespective of the sports discipline, the quality of the prediction rises with later occlusion points irrespective of the subject's experience (Loffing et al., 2014). Considerably more enlightening is the comparison of the prediction accuracy in two successive occlusion conditions. A significant increase in the prediction accuracy at the later occlusion condition indicates relevant information beneficial to successful anticipation - all within the considered time interval (Farrow et al., 2005; Loffing et al., 2014). A multitude of studies shows that experts are able to use information available early in the action progress to make distinct assumptions about the outcome of events. This data was collected and compared with more novice athletes, who demonstrated an inability to significantly extract any helpful cues. The certain time span depends on the considered type of sport. In badminton, for instance, the difference between expert and novice prediction performance is most evident in the period from approximately 160-180 ms prior to racket-shuttle contact (Abernethy & Russell, 1987a). Alternatively, in squash, experts (but not novices) are able to pick up information from events occurring even earlier than 160 ms before racket-ball contact (Abernethy, 1990a).

An early research study using the progressive temporal occlusion paradigm was published by Abernethy and Russell (1987a), who examined the temporal (Exp. 1) and spatial (Exp. 2) characteristics of the anticipatory cues used by expert and novice badminton players. Participants were asked to watch video-sequences of badminton strokes and to predict the landing position of the stroke. In Exp. 1 the display characteristics were manipulated by varying the duration of the stroke sequence that was visible. Five different occlusion conditions were put into effect and included: t1: Occlusion of the display occurred four frames (167 ms) prior to racket-shuttle contact; t2: Occlusion of the display occurred two frames (83 ms) prior to racket-shuttle contact; t3: Occlusion of the display occurred at the point of racket-shuttle contact; t4: Occlusion of the display occurred two frames (83 ms) subsequent to racket-shuttle contact; t5: No occlusion of the display occurred and all the outward flight of the shuttle was visible. Results revealed a significant interaction between playing proficiency and the temporal occlusion conditions, which was attributable to the superior performance of the expert badminton players during all occlusion conditions, with the exception of t1. Consequently, when display information is occluded at any time after 167 ms prior to racket-shuttle contact, experts showed a superior ability to use the available display information to predict the opponent's forthcoming stroke. Moreover, skilled players (but not novices) were able to extract and successfully use information in the period from t1 to t2 (167-183 ms prior to racket-shuttle contact), strongly suggesting a greater capability of expert performers to recognize early redundancy in the display of their opponent. Comparable research findings were delivered a few years later by A.M. Williams and Burwitz (1993), who examined the effect of playing-expertise on anticipatory performance in soccer penalty kicks. The study involved asking experienced and inexperienced soccer players to watch videos of penalty kicks which were occluded at four different points of time (120 ms prior impact, 40 ms prior impact, at foot impact and 40 ms after impact). Subjects were asked to make a perceptual judgement regarding which corner of the goal the ball was directed to. Prediction accuracy was shown to be higher when more visual information was available, however, both groups performed better than chance (> 25% correct predictions) across all conditions, leading to the conclusion that it is possible to anticipate the direction of a penalty kick from the preparatory movements of a penalty taker. Differences between experts and novices were most salient at early occlusion points (120 ms prior foot impact), indicating a better use of earlier sources of information. Abernethy (1990a) included an even earlier point of occlusion in his study on anticipation in squash (160ms prior to racket-ball-contact), in which an expert advantage was shown for all occlusion conditions. With an increasing degree of available visual information (a later occlusion point respectively) experts progressively reduced their lateral prediction error for the landing position of the strokes they were shown. Furthermore, experts performed better than chance at the earliest occlusion point, leading to the conclusion that experts may be able to use information earlier than 160 ms prior to racket-ball-contact to successfully predict stroke outcomes. In contrast, novice athletes only demonstrated a significant improvement in their anticipatory performance when ball flight information became available.

In large part, existing studies apply the temporal occlusion technique through a visual representation. For instance, video sequences are presented to subjects on computers or large screens in laboratory settings. However, assignment of the temporal occlusion paradigm is not only possible in a laboratory setting but also in a more realistic environment with the help of liquid-crystal spectacles (Milgram, 1987). For further clarification, liquid-crystal spectacles are special glasses which can be blacked out by the experimenter at a favored point of time. This process ensures that disposability of visual information can be temporally limited, which is similar to cutting out sections of a video sequence. At early times the occlusion spectacles were tested in research studies on perception in volleyball (Starkes, Edwards, Dissanayake, & Dunn, 1995). The advantage of these spectacles lies in the possibility to test motor reactions in a sport situation, e.g., during a squash match (Abernethy et al., 2001) or when preparing to return a serve in tennis (Farrow & Abernethy, 2003). This way, real demand structures are created by perception-action coupling. In order to reveal the full nature of the expert advantage, the importance of using experimental conditions and task demands that closely resemble the natural performance environment was consistently highlighted as a critical step in maintaining study validity (e.g., D. L. Mann et al., 2010).

Besides the question *when* athletes can successfully predict opponent's action intentions, one is interested *what* information from the visual display is used. Verbal reports (A.M. Williams & Burwitz, 1993) from test persons can provide first evidence. However, it is still indistinct if and to what extent the referred features are crucial to the prediction of event outcomes or intentions of others (cf. Loffing et al., 2014). In addition to the temporal occlusion technique, which is predominantly used to make out relevant time frames for the visual information pick-up, the spatial occlusion technique is used to identify discrete visual cues which have shown to be important for the prediction of an event outcome or the intention of an opponent. The spatial occlusion facilitates conclusions about the relative significance of different information sources (typically body parts or pieces of sport equipment) by examining the decrease of anticipation performance when vision on specific features is restricted. Generally, video material of sport situations provides a basis for the spatial occlusion of visual information. Miscellaneous information sources such as a particular body segment or the ball (Abernethy, 1990a; Abernethy & Russell, 1987a; A.M. Williams & Davids, 1998) are either hidden through opaque labels, e.g. black bars (Abernethy & Russell, 1987a; Hagemann & Strauss, 2006), or made „invisible" with the help of video editing software (Loffing & Hagemann, 2014b; Mueller et al., 2006). These two possibilities are pictured in Fig. 8.

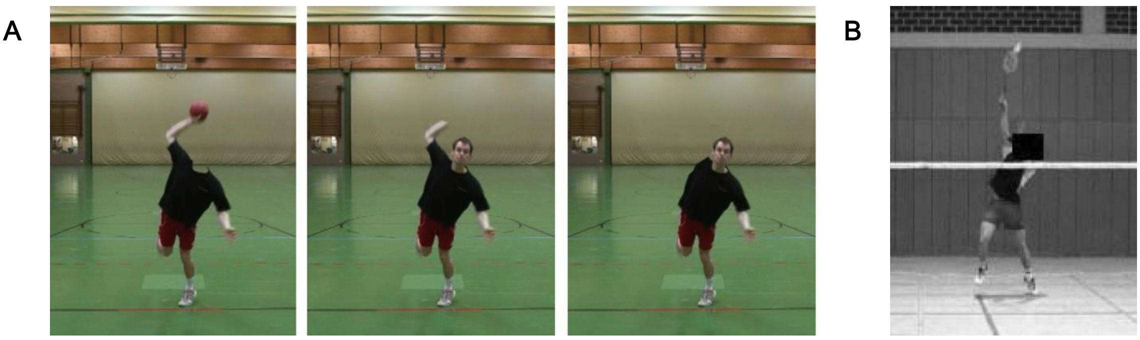


Fig. 8 Example for the use of spatial occlusion technique in video-experiments: **A.** Body segments made invisible via video editing software (Loffing & Hagemann, 2014a); **B.** Body segments hidden behind opaque labels (Hagemann & Strauss, 2006).

Loffing and Hagemann (2014b) used the spatial occlusion technique to identify the observers' reliance on locally versus globally distributed spatial cues when predicting type of throws in handball penalties. In their experiment, experienced and novice handball goalkeepers were asked to watch videos of penalties in which particular parts of the thrower's body or the ball (head, ball + hand, throwing arm + ball, upper body) were either removed or presented in isolation. Results showed that experts, as well as novices, can predict the type of throw even when only specific distal regions were present, such as the ball, the hand or the head. Additionally, experienced athletes benefitted from the availability of more distal and proximal regions when the upper body was visible, suggesting that experienced handball players rely on multiple globally distributed body regions. In line with these findings, other studies using the spatial occlusion paradigm showed that experts, in contrast to less skilled players, are able to use more global information from the opponent's body range. For example, skilled players in racket sports rely on information from the racket and the conjoint arm region when anticipating serves while less skilled players rely solely on the racket region (Abernethy et al., 2012; Abernethy & Russell, 1987a). Furthermore, experts seem to be more capable of predicting the outcome of an action based on the relative movement between adjacent body segments (Mueller et al., 2006). For instance, when receiving a bowl in cricket, experts use the relation between the hand position and the forearm as an information source instead of only using the wrist joint or forearm. Since the movement of proximal body segments (which are closer to the core) precedes the movement of more distal body regions, and therefore provides earlier information on the movement outcome, the findings coincide with the assumption that skilled players are able to extract meaningful information at an earlier stage of the movement and thus, are capable of making better response selections (Abernethy et al., 2012).

Utilization of the spatial occlusion technique is also possible in the field (Panchuk & Vickers, 2009), although its implementation requires some creativity. In their study on the control strategies used during the rapid interceptive actions of ice hockey goaltending, Panchuk and Vickers (2009) tried to apply the paradigm in a natural setting. They used two custom designed frames consisting of a body section and stick section with curtains hung from the top of the frame that could be slid open and closed to occlude the shooter's body parts or the puck on the shooter's stick and hands or from the goaltender's point of view (Fig. 9).

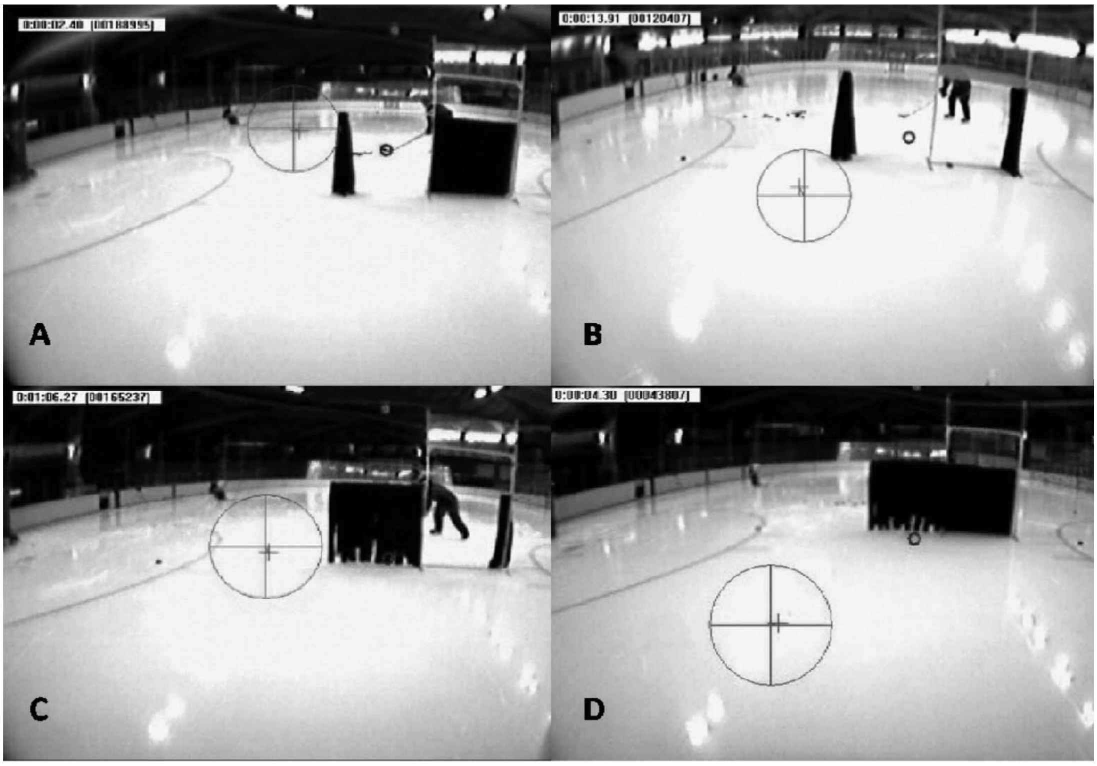


Fig. 9 The four occlusion conditions created using the occlusion device as seen from the goaltender's perspective (Panchuk & Vickers, 2009): shooter's lower body is occluded (**A**), shooter's upper body is occluded (**B**), stick and puck during delivery are occluded (**C**), all actions of the shooter occluded and only puck flight visible (**D**)

Furthermore, the temporal and spatial occlusion paradigms can be applied in a combined matter (Hagemann & Strauss, 2006), which allows for a high temporal and spatial resolution of the visual information pick-up. In their experiment, Hagemann and Strauss (2006) asked professional and amateur badminton players, as well as novices, to predict the direction of overhead badminton strokes. The presented movement sequences were manipulated by a combined spatial and temporal occlusion technique. Results showed that up to 160 ms before racket-ball-contact, the action of proximal body segments (trunk) was most relevant. However, after the 160 ms, the movement of distal body segments (arm, racket) was used as the main source of information for anticipating the forthcoming stroke.

Next to the temporal and spatial occlusion paradigm, the eye-movement registration is one of the most common methods for examining perceptual-cognitive expertise in sports. It is assumed that the attention path of a person is represented by his or her eye-movements. Therefore, the examination of someone's eye-movements aims to estimate what that person finds interesting, what raises his or her attention and how a person visually captures a setting (Duchowski, 2007). Hence, the recording and analysis of eye-movements is not only used in sport sciences but also in neuro-physiology, cognitive psychology, engineering science, ergonomics, marketing, advertising and computer science (Holmqvist et al., 2011). The instrument used for measuring eye-movement is conventionally known as an eye-tracker. Diverse eye-tracking-systems use different measuring methods (for an overview see Duchowski, 2007). Currently, the most common method is the cornea-reflex-method which is based on the registration of (infrared-) light reflexes on the cornea. In doing so, the eye is illuminated with infrared-light. The illuminated eye is then recorded with a monochromatic videocamera via a telephoto lense. The light reflex on the coordinates of the cornea and the pupil are extracted from the video material, and after the accordant equalization, the relative distance bettween the reflex and the pupil is exported as angular field (Spektrum Akademischer Verlag, 2011).

In the domain of perception and anticipation research in sport science, examinations of gaze behavior are predominantly used to determine what athletes are looking at in sport situations. This information can then be used to draw conclusions about what information from the visual field and the opponent's movement is relevant for successfully anticipating event outcomes or intentions of others. In doing so, both stationary and mobile eye-tracking systems are used, which record and analyze the different parameters of the gaze behavior, e.g., fixation location, fixation duration and saccades. In several research studies from the area of perception and action in sport, visual search strategies are examined with the help of eye-movement registration (e.g., Abernethy, 1990b; Goulet et al., 1989; Savelsbergh et al., 2002).

When comparing visual search strategies of experts and novices in squash, it becomes apparent that for both groups the racket area forms the major region of fixation, whereas the trunk area and the lower body were rarely fixated upon (Abernethy, 1990b). A significant main effect between the two groups is primarily shown due to the distinct expert-novice-difference in the fixation of the head region, the arm region and the contact zone (area of racket-ball-contact). Particularly, experts were shown to have had a considerably higher number of fixations on the head and arm region of the opposing player and a significantly lower number of fixations on the contact zone, when compared to their novice counterparts. The ascertained disparities in the distribution of fixations between expert and novice athletes indicate a difference in the visual search strategy; however, these do not seem to be sufficient in explaining the apparent expert-novice difference in the information pick-up. Goulet et al. (1989) examined the visual search strategies of expert and novice tennis players in a video-based laboratory experiment. In addition to eye movement registration, they used the temporal occlusion paradigm to examine the contribution of the separate stroke phase in order to identify stroke type (topspin, slice and drive). They hypothesized that expert players use a more efficient search strategy and are able to effectively use information from earlier phases prior to ball flight. Indeed, experts outperformed novices when asked to predict stroke type. Through analysis of the relationship between the different occlusion conditions and the prediction accuracy it became apparent that experts use information from earlier phases of the movement and that the preparatory and ball flight phases do not imply any information sufficient to identifying stroke type. In contrast, the novice athletes were shown to need the whole movement, including racket-ball-contact, in order to make reliable predictions. However, contrary to their expectations and from results obtained in earlier studies on visual search in basketball (Bard & Fleury, 1976), experts made significantly more fixations. Overall, even though some differences emerged in the visual scanpath analysis in the study of Goulet et al. (1989), experts and novices centered their information selection to the same areas. In the ritual phase (ball bounces and foot positioning), both groups focused on the server's shoulder/trunk and head zones, during the preparatory phase (beginning with the elevation of the arm holding the ball and ending with the apex of the ball trajectory) they focused on the ball and its anticipated position, and during the execution phase (starting with the server’s knee extension and finishing at racket-ball-contact) on the ball and the racket position. Based on their respective findings, both Goulet et al. (1989) and Abernethy (1990b) reported that the analysis of eye movements is helpful but does not provide sufficient information for identifying factors that explain expert-novice differences. Abernethy and Russell (1987b) concluded from their research on badminton that the main reason for the observed differences in perception between expert and novice subjects does not lie in the visual search strategy per se, but rather in how the assimilated information is used. While expert and novice athletes clearly differ in their ability to use early information sources, as well as gaining useful visual cues from the arm region, both groups demonstrate more or less a similar visual search strategy.

A persistent limitation for the registration of eye-movements is the fact that peripheral vision cannot be measured. However, experts in complex sport situations, especially in team sports, seem to be able to simultaneously monitor the various events occurring around them (e.g., A. M. Williams & Davids, 1997). A promising method of peripheral vison assessment, which may assist in further clarifying the role of peripheral vision, is the use of gaze-contingent video displays, where the part of the video shown depends on the participants gaze location (e.g., Hagemann, Schorer, Cañal-Bruland, Lotz, & Strauss, 2010). Moreover, A. M. Williams and Davids (1997) suggest that when peripheral vision is employed to extract task-specific information, verbal reports may provide a better measure of selective attention.

Generally, findings on visual search behavior have supported the evidence surrounding utilization of the spatial occlusion paradigm, with respect to the idea that experienced athletes spend more time fixating on body parts and events that occur earlier in the kinematic chain (Abernethy et al., 2012). For example, when anticipating a tennis serve, tennis players were shown to observe their opponents shoulder rather than their racket (Goulet et al., 1989; A.M. Williams et al., 2002). Likewise, when anticipating a penalty shot, soccer goalkeepers were shown to observe the non-kicking leg rather than the kicking leg of a penalty taker (Savelsbergh, Van der Kamp, Williams, & Ward, 2005; Savelsbergh et al., 2002). This goes with the fact that throwing, shooting or hitting movements follow a proximal-to-distal activation of body parts, and that experts, in contrast to their novice counterparts, are aware of and familiar with the kinematic evolution of these movements (Abernethy et al., 2001).

Yet another approach to examine which visual information is crucial to the anticipation of actions in sport rests upon the fact that human movements have systematic and quantifiable biomechanics. Therefore, the kinematics of such movements can be adequately represented with the help of the point light method. The point light method originated from the work of Marey (1895/1972) but became popular through the work of Johansson (1973). In order to create a point light video sequence, markers are placed at certain points of the subject’s body, normally at the joints, of which the movements are then tracked and registered via a special video or 3D-recording-system. By using this method, such sequences enable researchers to incorporate the essential kinematic information from the movement while limiting further visual information such as contours, texture, shape, color and so on, as they are not included in the graphical material (Cañal-Bruland, 2007). Amongst others, complex actions like whole body movements (Dittrich, 1993), facial expressions (Bassili, 1978) and sign language (Poizner, Bellugi, & Lutesdriscoll, 1981) can be identified on the basis of point light representations. In addition to these functions, the point light display has also been shown to provide sufficient information when attempting to recognize the gender of a walking human (Pollick, Kay, Heim, & Stringer, 2005). This is an indicator for the meticulous coordination between the visual system and biological movements. Given the evidence presented regarding the point light method and analysis, it is suggested that utilization of this instrument is appropriate when investigating perceptual-cognitive expertise in sports (Abernethy et al., 2001; Huys, Smeeton, Hodges, Beek, & Williams, 2008; Loffing, Wilkes, & Hagemann, 2011). The advantage of this technique lies in its ability to manipulate various movements without altering the visual display (Huys et al., 2008) or to imbed point light animated actions in arbitrary visual environments (Loffing & Hagemann, 2014a). For example, Loffing and Hagemann (2014a) variegated the position of a tennis player on the field, with the help of point light sequences, while keeping the kinematics of the player constant in order to isolate the effect of the opponent's position on the prediction of action outcomes (see chapter 2.4.2). In summary, research studies using this technique show that the expert advantage in visual information pick-up does not result from figural or structural information, such as shape, color and contour, but rather lies in the use of the basic biomechanical (kinematic) properties of the movement pattern (Abernethy et al., 2012).

2.4.2 Contextual cue usage

Besides the usage of bodily cues, experienced athletes integrate non-movement related, contextual cues to successfully anticipate future action outcomes. This suggestion is supported by previously reported research, showing that experts can foresee action outcomes better than random chance would predict, even before an opponent has initiated a movement (Abernethy et al., 2001). Furthermore, when asked about factors affecting their decision making in domain-specific sport situations, professional athletes highlight opponent specifics, external and situational context, as well as intuition, contiguous to opponent’s movements, as potential factors (Schlaeppi-Lienhard & Hossner, 2015).

In this chapter, findings on various types of contextual information will be presented. Please note that, initially, there will be no systematization of these contextual cues carried out, but rather research findings pertaining to the examination of specific contextual cues will be summarized. Subsequently, chapter 2.4.3 will focus on a systematization of these cues and on the interaction of contextual and kinematic cue usage during the anticipation process.

While the perception of kinematic cues when anticipating opponent’s action intentions has been extensively studied in past research, the examination of the contribution of contextual cues has been vastly neglected (Cañal-Bruland & Mann, 2015). However, in recent times, there has been an increasing amount of interest generated regarding examination of the role of contextual cues for anticipatory behavior in time-constrained sport situations (e.g., Crognier & Féry, 2005; Farrow & Reid, 2012; Loffing & Hagemann, 2014a; Loffing et al., 2015; D. L. Mann et al., 2014). These contextual cues can be of a different nature. Moreover, different contextual cues vary in their temporal availability and significance to an athlete in a concrete sport situation.

During their development, expert athletes develop not only outstanding motor and perceptual skills, but also accumulate domain-specific knowledge about situational probabilities. This means, in specific situations, experts have a prior-assumption “that one action is more likely to occur than another one” (Cañal-Bruland & Schmidt, 2009, p. 236). For example, while expert tennis players are aware that cross-court shots occur more frequently than longline shots (Loffing, Hagemann, & Strauss, 2010; Martinez-Gallego, Guzman, James, et al., 2013) and consequently may bias their expectations when awaiting an opposing player’s shot (Loffing & Hagemann, 2014a; Loffing, Sölter, Hagemann, & Strauss, 2016), novices are likely to lack this sport-specific probability distribution. The use of situational probabilities may facilitate (and/or prime; Paull & Glencross, 1997) successful anticipatory performance at very early points of time, before the opponent’s movement kinematics visually occur (Abernethy et al., 2001).

The subjective probabilities assigned to certain action outcomes in a specific sport situation (e.g., a higher probability for a cross court shot in tennis) result from the accumulation of various information. In a research study by Alain and Sarrazin (1990) defending squash players, in actual game competitions, consistently reported the use of varying sources of prior information, such as the opponent's playing habits and their ability to aim the ball where they want, while awaiting an opponent's action. The authors suggest that information occurring in the specific game situation (e.g., the player's position on the court) activates correspondent information stored in memory, which is used to frame tentative expectancies and "to orient the search for subsequent information which could serve to update these expectancies" (p. 196).

The subjective probability assigned to a certain action outcome has been shown to determine how an athlete chooses to prepare (Alain & Sarrazin, 1990; Alain, Sarrazin, & Lacombe, 1986). Hence, the knowledge or belief that in a certain situation, one action is more likely to occur than another has the potential to result in a biased response behavior (Alain & Proteau, 1978; Mueller et al., 2006; Proteau, Levesque, Laurencelle, & Girouard, 1989). Several research studies deliver scientific evidence for a biased behavior of experienced athletes. For example, Mueller and Abernethy (2006) detected that world-class cricket batsmen showed a tendency to expect a ball of full length, rather than a short ball, unless ball flight information became available. The authors suggested that this biased expectation reflects a particular skill-related strategy, given that in cricket, balls of full length occur more frequently than other types of delivery. Cañal-Bruland and Schmidt (2009) came to a similar conclusion when examining expert athletes who followed a set of specific strategies that allowed them to enhance their possibility of a successful reaction in time-constrained situations. In their experiment, skilled handball goalkeepers, field players and novices were asked to judge penalty shot movements as non-deceptive or deceptive. From this example, skilled goalkeepers, in contrast to the other groups familiar with facing penalty shots, showed a bias towards judging an action as deceptive. The authors offer two explanations for their findings. The first explanation postulates that goalkeepers might rely on their acquired knowledge about situational probabilities of deceptive and non-deceptive movements in penalty situations; and secondly, it is theorized that goalkeepers may follow a simple cost-benefit ratio in an attempt to maximize their keeping rates; in other words, they prefer to judge an action as fake due to their experienced costs of missing deceptive trials. That means in past penalty situations when they had wrongly judged a throwers action as non-deceptive (e.g., started to move toward the wrong direction) they were less likely to still save the ball as compared to when they had wrongly judged an action as deceptive (and waited longer). This might be due to the fact that correcting a false movement takes longer time than initiating a movement right away. An analogous strategy was found for batting in baseball (Cañal-Bruland, Filius, & Oudejans, 2015). From this example, experienced batters showed a tendency to “sit on a fastball”, which implies they favored expecting a fastball (fast type of pitch) rather than a change-up (slow type of pitch). Such a strategy might be beneficial for the batters, helping them to react and initiate a swing early enough to successfully bat, irrespective of the type of pitch (Cañal-Bruland et al., 2015). These findings overlap with evidence for cricket batting (Mueller et al., 2006), but at the same time, point to potential disadvantageous effects of following subjective probabilities when an expectation is in fact violated (see also Gray, 2002; D. L. Mann et al., 2014).

As previously mentioned, a variety of information can be used to determine if an athlete considers one action more likely to occur than another, thus insinuating that subjective probabilities can be deduced from different contextual cues. In the following sections, specific contextual cues will be reviewed and analyzed regarding their facilitating or hindering effects on visual anticipation of opponent’s action intentions.

Action preferences of an opponent

At the elite level, as well as at an amateur level, athletes in sport competitions are repeatedly faced with the same opponents due to the limited number of top level players or the regional affiliation. Oftentimes in these competitive sport situations, athletes become familiar with their opponent’s preferences, strengths and weaknesses. Additionally, at an elite level, extensive statistics about most of the players are available for athletes and coaches (e.g., Liu, Gomez, & Lago-Penas, 2015). It is therefore consequential to assume that this prior-knowledge about the preferences of an opponent may influence an athlete’s expectation of an action outcome. In an early research study, Miki, Tsuchiya, and Nishino (1993) showed that when competitors had an expectation of an opponent’s competence, either positive of negative, they attended to this expectation and matched the opponent's attributes to the initial expectancy. At the same time, they neglected the opponent's discrete attributes.

On the basis of game observation, and particularly by fans, professional soccer player Arjen Robben, of FC Bayern Munich, is rumored to always “pass by on the left” in 1-on-1 situations close to the opposing penalty area. This previous knowledge has the potential to influence the expectations of a defensive player, who finds themselves confronted with Robben in a soccer game. While such previous knowledge has the potential to benefit anticipation, it also has the ability to negatively impact it, if Robben decides to suddenly pass by on the right.

In two different experiments, Barton, Jackson, and Bishop (2013) compared the costs and benefits of having prior statistical information about the preferences of an opponent in soccer. In a video-based anticipation test they compared the ability of both expert and novice subjects to predict a direction change of an oncoming player in a simulated 1-on-1 situation, with or without a deceptive movement. Prior to each presented video-block the participants were given statistical information about the likelihood of the opponent changing direction to the left or to the right (83%/17%, 67%/33%, 50%/50%). They asserted that experts were less susceptible to deceptive movements and exhibited better predictions compared to their novice counterparts. In the second experiment they systematically varied the occlusion point of the video across two conditions (at foot-ball-contact and 80ms after). It became apparent that at early occlusion conditions both experts and novices benefitted from statistical information. Results from the study indicated that best prediction accuracy was reached in the 83%/17%-condition compared to the 67%/33% and 50%/50% (neutral) conditions. The advantage of statistical information appears stronger for videos showing deceptive movements, which leads us to assume that the uncertainty caused by a deceptive movement leads the observer to increasingly rely on prior probability information and tendencies of an opponent.

Similarly, Navia et al. (2013) provide further evidence of the beneficial effects that can result when prior knowledge of an opponent's shot direction preference is utilized by soccer goalkeepers during anticipation of a penalty shot. In this experiment, researchers examined the defensive behavior of goalkeepers when facing penalty kicks in a real setting under four conditions. The probability that a penalty was kicked to the right or left side of the goal was varied as well as whether or not the goalkeepers were informed about the probabilistic distribution (no information, 50%/50%, 80%/20%, 20%/80%). Results of the study demonstrated that: (1) goalkeepers clearly benefitted from the use of prior statistical information; and (2) a strong asymmetry in the penalty-taker's shot direction preference (i.e., 80% to the right or left side) led to improved anticipatory performance of goalkeepers, in terms of diving to the same side that the ball was directed and earlier initiation of the dive. This particular study, conducted by Navia et al. (2013), was the first to demonstrate that situational information has the potential to enhance the spatial and temporal aspects of interceptive actions *in situ*. Therefore, it clearly depicts a methodological advancement when compared to video-based research studies (e.g., Barton et al., 2013), that often require button-press-responses. However, the authors acknowledge that the small number of participants (9 goalkeepers) considerably limits the power for detecting differences as a function of situational information, especially with regard to gaze characteristics, which were also collected during this study. Moreover, the authors point to the need to test more skilled goalkeepers in order to examine the interaction between situational information and individual capabilities like agility, which has also been suggested as a factor affecting the timing of a dive (Dicks et al., 2010).

It has been suggested that knowledge of an opponent's action preferences facilitates anticipation of action intentions. However, there are also costs associated with relying on such knowledge. In a video-based experiment, D. L. Mann et al. (2014) tested the ability of skilled handball goalkeepers to anticipate direction of penalty throws before and after a training intervention. In the pre- and post-test, subjects were asked to predict throw direction of two penalty-takers of whom one showed a tendency to throw 75% of balls to the upper left side. For the intervention, participants were divided into two training groups. One group anticipated throw directions performed by two players who threw equally to all four directions (NP-Training group) while the other group viewed two players, both of whom had a preference to throw 75% of all balls to the upper left side (AP-Training group). Performance of the AP-Training group in the post-test revealed that knowledge about an action preference of the thrower, benefits successful anticipation of penalty throws (measured by response accuracy and response time) only when the opponent continued to bias their throws towards their preferred direction. If a thrower did not show the preference he exhibited during the training-phase, participants' performance declined during the post-test. The findings of D. L. Mann et al. (2014) were specific to experts, but recently replicated and extended in novices (Loffing, Stern, & Hagemann, 2016). Similar disadvantageous effects of expectation biases were found for baseball batting (Cañal-Bruland et al., 2015). D. L. Mann et al. (2014) pointed to the possibility that action preferences could differentially influence anticipatory judgements made by the perceptual and motor systems. This further suggests that knowledge about action preferences could lead to even stronger changes in response accuracy when producing a motor response as opposed to a button-press, as was the case in their study. Alternatively, a decrease in the influence of situational information on anticipatory judgements when asked to perform a motor reaction is also possible, as a stronger perception-action coupling may be more impervious to 'interruption' by situational information (cf. D. L. Mann et al., 2014).

The current literature indicates that knowledge of an action preference has the ability to both benefit and impair anticipation of action intentions. If we use this concept to evaluate the context of an 1-on-1 situation with Arjen Robben the following scenario would go as follows: If Robben tries to pass by on the left side, „as always", and therefore acts compatibly with the expectation, it's beneficial for the opponent to integrate prior knowledge in their decision. However, if Robben suddenly acts contrary to the expectation and tries to pass by on the right, the opponent is more likely deceived through his or her prior knowledge. Ideally, from the perspective of the opponent, it is advantageous to have some degree of certainty that Robben will act consistently with his past behavior. From the perspective of Robben, if we assume that his opponent is aware of his action preference, he would be best advised to act in an inconsistent manner and try to pass by on the right. However, Robben may possess this particular action preference given that he is simply more versed at performing his preferred action. Choosing a different option may result in a decrease in movement quality and in the probability of executing a successful action.

The use of prior-knowledge about the strengths, weaknesses and tendencies of an opponent in a sport competition can help form expectations that may be beneficial in situations where we have to anticipate a forthcoming action of our counterpart. Nonetheless, it is widely known that an athlete's performance or decision making ability can strongly depend on their actual condition on the day of competition. Let us assume one has built up a certain opponent profile based on past competitions or statistical analysis (e.g., an opponent in tennis usually having a weak backhand, is playing mostly from the backcourt, etc.). As competition progresses, this profile has to be constantly updated (e.g., the opponent is having trouble with the forehand today or is charging the net more often, etc.). The study of D. L. Mann et al. (2014), as mentioned previously, clearly demonstrates how the availability of prior-knowledge can also be disadvantageous if an opponent behaves in contrary to the expectations. Therefore, a more up-do-date profile has to be developed. Analyses of verbal reports during real competitions revealed that expert athletes continuously update conditions about their opponent's tendencies and weaknesses and then use them to generate profiles which they use to plan upcoming games or to make predictions about how an opponent will behave in an upcoming situation (McPherson, 1999a, 1999b, 2000). Alternatively, it has been shown that novice athletes also notice the strengths and weaknesses of their opponent's however, they do not further interpret such information or use it for planning tactics (McPherson, 2000). By analyzing the think-aloud protocols of various participants when viewing videotaped baseball games, McPherson (1993) detected that expert players, when compared to non-players, build condition profiles about the pitcher and the preceding batters' behavior. To further exemplify this, McPherson (1993) states that "the experts generated self-regulatory strategies to update, check, and modify their predictions of pitcher characteristics" (p. 304). Correspondingly, McRobert, Ward, Eccles, and Williams (2011) found that cricket-batters improved batting performance in a virtual batting task, as well as provided more detailed verbal reports of thinking, when they viewed their opponent multiple times (high context) as opposed to when they responded to their opponent without previously seeing them bowl (low context). In both conditions (low and high context), skilled batters were shown to provide an increase in the number of evaluations, predictions and deep planning verbal statements, which is congruent with the proposed adaptions in LTM and the development of LTWM skill (see chapter 2.2.3; Ericsson & Kintsch, 1995; McPherson, 1999b).

Newell (1986) categorized context-specific variables that influence decision making and performance (here in baseball-batting) as either objective or subjective. While variables such as the perceived ability of an opponent (as well as e.g., the level of tactical initiative, see below) can be assigned to the category of subjective demands, items such as game score or past history of the opponent belong to the category of objective, context-specific demands. However, as Newell acknowledges, "while the situational variables can be quantitatively categorized, this does not preclude the possibility of batters perceiving the same situations differently and ultimately, making different decisions based on the same objective data" (p. 523).[5]

Game score

In team-sports such as soccer or baseball, the influence of the game score may make particular actions in one situation more likely than another. Furthermore, a team or a player who is behind in a game will probably change their game strategy and resort to using a more offensive, and potentially riskier, style of play. For example, an offensive player in soccer, whose team is behind, would rather attempt to score a direct goal instead of choosing to pass in order to press for a tie. In a similar situation in baseball, a pitcher will probably throw faster balls to impede opposing batters' successful bats. Therefore, it can be assumed that experienced baseball batters generate expectations about the upcoming pitch on the basis of the pitch count: "Certainly the pitch you anticipate when the count is 0 and 2 (a curve ball probably, if the pitcher has one) is not the pitch you anticipate when the count is 2 and 0 (fastball, almost without exception)" (T. Williams & Underwood, 1970, p. 30). Furthermore, it has been found that in baseball, a certain level of comprehension of game score specificity is evident, when preparing to bat (Gray, 2002; Paull & Glencross, 1997). Following Paull and Glencross (1997), who detected that experts and novices use strategic game information to set probabilities about forthcoming events in baseball, Gray (2002) discovered that expectations of baseball batters varied as a function of game score. In a virtual batting task, experienced college players were asked to swing a baseball bat at a simulation of an approaching baseball. The simulated ball was displayed on a monitor that was viewed from a distance of 3.5 m in a dimly lit room. By increasing the angular size of the ball, a sensation of motion toward the batter was created. At the end of the baseball bat, a sensor tracking the position of the bat was mounted. Spatial and temporal swing accu-

[5] Please note that this aspect will be picked up on later in chapter 2.4.3.1, which focusses on the determinants of kinematic and contextual cue usage in the anticipation process.

racy was measured to test whether batters were influenced by pitch count (and other factors). In fact, Gray (2002) showed that pitch count had significant effects on batting accuracy. Precisely, results indicated that baseball batters expected balls with higher velocity from the pitcher when the pitching team was two points behind compared to when the batters team was behind. As rightly stated by the authors, the baseball batting simulation used in this study clearly depicts a methodical advancement in this research area by combining fine control over stimulus parameters with realistic and active motor responses. However, as only ball flight information was available to the observers, this may have artificially favored the influence of contextual information (here: pitch count) on anticipatory behavior. To enhance the external validity of research studies examining the role of contextual cues in the anticipation process and to preemptively counteract the overvaluation of such cues, the process of manipulating contextual information while simultaneously keeping kinematic information constant, may be a promising approach (e.g., Loffing et al., 2015).

Additional indication of score-dependent anticipation was suggested by Farrow and Reid (2012) for the return of serves in tennis. In a video-based experiment researchers asked skilled tennis players, displaying different levels of development, to predict the location of tennis serves. In doing so, game score and resultant serve location were systematically manipulated. The researchers found that older players, in contrast to less-experienced younger players, picked up better on the occurrence of a certain service pattern. As well, the authors have highlighted the importance of situational probabilities as it relates to successful anticipatory performance, of which can result from game score, for example.

Tactical initiative

The level of initiative or control that an athlete or team has in a certain situation may influence their future actions and at the same time, the expectations of an opposing player or team. If we think of tennis for example, the progress of the ongoing rally can have an impact on the player's anticipative behavior. Additionally, the level of tactical initiative in which a player finds himself in during this moment can determine what they expect and ultimately decide to do next (Crognier & Féry, 2005). In a simulated on-court experiment, Crognier and Féry (2005) tested experienced male tennis players and compared their anticipation of passing shots from an opponent under three different conditions that varied in their level of tactical initiative (reflecting the possibilities of controlling rallies). Each game situation finished with a passing shot from the opponent that the participant had to intercept with a volley stroke in the absence of visual information (vision occluded at the point of racket-ball-contact with the help of liquid crystal spectacles). Participants were more accurate in their prediction, and ultimately performed better, when they were in steady control of the rally (high level of tactical initiative), compared to when their level of tactical initiative was moderate or weak. The decision of the player during the offensive phase was shown to have likely influenced the direction of the opponent's strokes. Furthermore, as the initial playing possibilities of each opponent was reduced, the players were expecting a particular response from their opponent (cf. Crognier & Féry, 2005). The realistic setting of this study allowed the authors to investigate the actual anticipation and decision making processes used during the game and to maintain the natural coupling of perception and action. However, the usage of liquid crystal spectacles during this study presents a limitation with respect to the control of occlusion time, as the spectacles had to be manually closed by an experimenter. Still, these spectacles have been used to successfully implement temporal occlusion paradigms in real-world tasks (Starkes et al., 1995). Another limitation of the experiment is the selection of a single-skill level participant group, restricting the interpretation of the results with regard to a possible expertise-dependent usage of contextual cues (this aspect will be taken on in chapter 2.4.3.1). Therefore, it would be desirable to include groups of different skill levels in future experimental designs of a similar study, in order to facilitate greater generalization of the obtained results.

On-court position

Athletes frequently report the use of a player's position on the court as a relevant source of information when anticipating the action intentions of an opponent during a game situation (Alain & Sarrazin, 1990; Schlaeppi-Lienhard & Hossner, 2015). Furthermore, by examining ball trajectory data from various professional men's single tennis matches, Loffing and Hagemann (2014a) found that shot direction probability varied as a function of a hitting players position on the court. In other words, the more a player was positioned away from the midline, the higher the percentage of cross-court shots.

The probability for a cross-court shot declined again for the most outer zone, possibly due to tactical constraints imposed on the hitting player. In a subsequent video-based anticipation experiment Loffing and Hagemann (2014a) manipulated the on-court position of opposing players with the help of point-light animations (previously described in chapter 2.4.1), while keeping their movement kinematics constant across various positions. Through this exercise they found that experienced players were more susceptible to positional information than novice players. In addition, the more the hitting player was positioned away from the midline, the more likely it became that skilled subjects expected them to execute a cross-court shot. With increasing availability of kinematic information from the hitting movement (i.e., with later occlusion points), the influence of on-court position on the prediction of action outcome decreased. The authors assumed that a formation of expectations concerning an opponent's action on the basis of contextual information, such as the player's position on the field, can possibly help to narrow down response possibilities and optimally prime a reaction.

Outcome of preceding events

Athletes in game situations continuously receive feedback on the outcome of both their own actions and their opponent's actions, and are likely to store this information in their memory (see chapter 2.2.3). Consequentially, in subsequent situations when they revert to their memory to plan an (re-)action, the knowledge of the outcome of the previous events may affect their expectations regarding future events. First evidence of this phenomena in sports was found by Gray (2002), who examined the influence of prior pitch sequence on baseball batting performance. In his experiment, Gray (2002; Exp. 2) asked six male, college-level, baseball batters to swing a baseball bat at a simulation of an approaching baseball. In each trial, the batters received feedback on the outcome of the pitch and their performance. The results showed that temporal and spatial accuracy of bats were influenced by preceding sequences of pitch speeds. In particular, performance on fast pitches was improved when the pitch followed three consecutive fast pitches. Accordingly, performance on fast pitches was impaired when it followed three slow pitches. This indicates the tendency for baseball batters to "sit on a fastball" (for similar conclusions see Cañal-Bruland et al., 2015). However, as Gray (2002) acknowledges, participants here were only confronted with ball flight information, unlike in a real game situation where the pitcher's kinematics are visible. As both contextual and kinematic cues are assumed to influence anticipation in sport situations (e.g., Buckolz et al., 1988), the absence of kinematic information in this experiment may have artificially increased the participants' reliance on the outcome of the previous pitches. A recent study conducted by Loffing et al. (2015) addressed the above issue and found further evidence that preceding events, or rather sequences of preceding events, influence the expectations placed on an opponent's action intentions, even in the presence of kinematic information. In two video-based experiments, researchers asked expert and novice volleyball players to anticipate the type of shot they were about to receive (lob vs. smash). In doing so, they varied shot type in the preceding four trials, so that either four lobs, four smashes or an alternating pattern forewent the shot of interest. The alternating pattern was integrated to test whether or not the effect reported by Gray (2002) is specific to sequences of identical outcomes (e.g., three fast pitches in a row) or if it may also occur in trials that follow another sequential pattern, e.g., events with alternating outcomes. It was shown that patterns of previous action outcomes bias visual anticipation of action outcome in subsequent trials. Specifically, volleyball players as well as novices preferentially expected the continuation of an attack pattern (e.g., they expected a smash after four consecutive smashes), irrespective of whether it was a sequence of identical or alternating outcomes. Interestingly, these findings are in line with related research in the field of experimental psychology (e.g., de Lussanet, Smeets, & Brenner, 2001, 2002; Huettel, Mack, & McCarthy, 2002) which has suggested that people are highly sensitive to sequential patterns in their environment, and are actively searching for and relying on such patterns to lead their future expectations and behavior (cf. Loffing et al., 2015).

As this contextual cue constitutes the basis for the research studies that were realized within the framework of this dissertation, the theoretical background of sequence judgements and expectations of sequences will be elaborated on in chapter three.

Environmental conditions[6]

Aside from the previously reported contextual information, environmental conditions, such as the climate or the nature of the ground, can potentially affect the expectations we have on an upcoming sports competition or the anticipation of a particular situation outcome during a game. Among others, Buckolz et al. (1988) refer to environmental conditions as a relevant contextual source for the a priori information sought in time-constrained sport situations. For example, the playing surface in a tennis match can strongly influence the style of play and consequently, the expectations of players. World championship tennis, e.g., the four Grand Slam tournaments, is characterized by play on different surfaces. While both the Australian and US Open are played on hard acrylic courts, Wimbledon is played on grass and the French Open (often referred to as Roland Garros) is played on clay. It is well known that the grass surface is 'fast' while the clay and synthetic surfaces are 'slow' which has generated much interest regarding the effect that surface type may have on tennis play. On faster surfaces, such as grass, the higher ball-velocities and associated movement speeds allow for fewer shots per rally and shorter rally lengths (Hughes & Clarke, 1995). O'Donoghue and Ingram (2000), who examined the strategies used by elite male and female players on different surfaces in Grand Slam tournaments, found that: (1) women's rallies were longer than men's rallies and (2) rallies on a clay surface were significantly longer than those on hardcourt or grass. Longer rally duration was associated with a greater proportion of baseline rallies. It is therefore reasonable to assume that such environmental conditions influence players' expectancies towards their opponents' behavior. With this in mind, it is possible that a player might expect a riskier shot on a fast surface, when compared to the same situation on a slower surface, e.g. a clay court, because the same executed shots will have different effects depending on the surface. If we remain with tennis, another environmental condition regarding the incident solar radiation might play a significant role when anticipating an opponent's action. If the opposing

[6] To my knowledge, there is so far only little scientific research regarding the direct influence of environmental conditions (e.g., playing surface, climate, etc.) on the anticipation of action intentions in sports (e.g., Schlaeppi-Lienhard & Hossner, 2015). Therefore, only assumptions about potentially relevant factors can be made at this point. Nevertheless this section is integrated in the chapter, given that the significance of such environmental conditions seem apparent and that a comprehensive survey of contextual cues is attempted to be presented here.

player looks straight into the sunlight when executing a serve, we might expect a weaker shot than if the sun was shining from behind them. Additionally, in every sport that is played outside, the temperature has the ability to influence our expectations on the course of play and the behavior of our opponent in certain game situations. This is due to the fact that game tactics often have to be adjusted to the current climatic conditions and thus the demands on the human physique and fitness level.

Summary

As was clearly depicted in this chapter, cumulative evidence suggests that in sport situations a variety of information outside an opponent's action, referred to as contextual cues (e.g., Buckolz et al. 1988), is integrated into the anticipation process. Table 2 provides a systematic overview of the previously outlined contextual cues that have been studied in terms of their relevance for anticipatory decisions.

Tab. 2 *Studies examining the role of contextual cues for anticipatory performance in sports.*

Contextual cue	Sport/Reference	Purpose
General action/ event probabilities	*Squash* Alain et al. (1986)	Examined if performers choice of preparation state is a conjoined consideration of both, probability of an event and time pressure.
	Squash Alain and Sarrazin (1990)	Examined cognitive strategies of defending players when choosing among different states of preparation with the help of verbal protocols. One of the aims was to verify that subjective probabilities assigned to potential attacks are used in choosing preparation state.
	Cricket Mueller et al. (2006)	Examined the ability to pick-up advance information to anticipate the type and length of balls bowled by swing and spin bowlers.
	Handball Cañal-Bruland and Schmidt (2009)	Examined the impact of motor and perceptual expertise on distinguishing deceptive and non-deceptive actions. Tested the hypothesis that differences in perceptual judgments on deceptive movements vs. non-deceptive movements can be a result of response bias.
	Baseball Cañal-Bruland, Filius, and Oudejans (2014)	Validated if baseball batters show an action bias, specifically, the strategy to expect a fastball (a fast type of pitch) rather than a change-up (a slower type of pitch) commonly referred to 'sitting on a fastball'.

Action preferences (opponent)	*Cricket* McRobert, Williams, Ward, Eccles, and Ericsson (2007)	Examined whether facing the same opponent several times in a row influences batting performance in cricket.
	Soccer Barton et al. (2013)	Examined costs and benefits of prior statistical information about opponent's preferences when anticipating action intentions.
	Soccer Navia et al. (2013)	Examined if prior knowledge about action preferences of a penalty kicker influences goalkeepers performance.
	Handball D. L. Mann et al. (2014)	Examined how anticipatory performance in handball is influenced by exposure to action preferences of an opponent.
Game score	*Baseball* Paull & Glencross, (1997)	Examined what visual information is used by baseball players when anticipating pitches, and how anticipatory performance can be improved by usage of prior probabilities set with the help of strategic game information (e.g., game score).
	Baseball Gray (2002), Exp. 3	Examined the effect of pitch count on batting performance in baseball.
	Tennis Farrow and Reid (2012)	Examined the contribution of situational probability information (e.g., game score) on anticipatory performance of tennis players from different stages of development.
Event history	*Baseball* Gray (2002), Exp. 2	Examined the effect of the history of previous pitches on batting performance in baseball.
	Volleyball Loffing et al. (2015)	Examined the influence of patterns of previous outcomes on anticipation of volleyball attacks.
Tactical initiative	*Tennis* Féry and Crognier (2001)	Examined the influence of tactical significance of a game situation on anticipation of strokes executed in this situation in tennis.
	Tennis Crognier and Féry (2005)	Examined the influence of the level of tactical intiative of an observer on his anticipation of strokes in tennis.
On-court position (opponent)	*Squash* Abernethy et al. (2001), Exp. 2	Examined the role of kinematic and situational probability information in squash.
	Tennis Loffing and Hagemann (2014a)	Examined the influence of opponent's position on the field on anticipation decisions in tennis.

When it comes to the examination of anticipation-relevant contextual cues, it seems like a rather unsystematic 'shot-gun' approach has been implemented. To date, the majority of existing studies focus on the examination of one particular contextual cue (e.g., on court position, game score, etc.) and its influence on future expectations rather than aligning them with other contextual sources. However, it is suggested that the anticipation process is characterized by the continuous integration and weighting of information derived from various contextual sources and current sensory input (e.g., visual perception of opponent's kinematics) (cf. Loffing et al., 2015). Therefore, it is necessary to consider the role of contextual cues in a larger framework.

2.4.3 Temporal availability and interaction of contextual and kinematic cues

When anticipating an opponent's action intentions in sport, athletes may rely on both kinematic information from the movements of their counterparts and contextual cues outside the opponent's action. It is suggested that this information is continuously integrated and weighted during the anticipation process. Fig. 10 attempts to illustrate the temporal availability and interaction of contextual and kinematic cues in the anticipation process, using the example of an opponent's pitch in baseball.

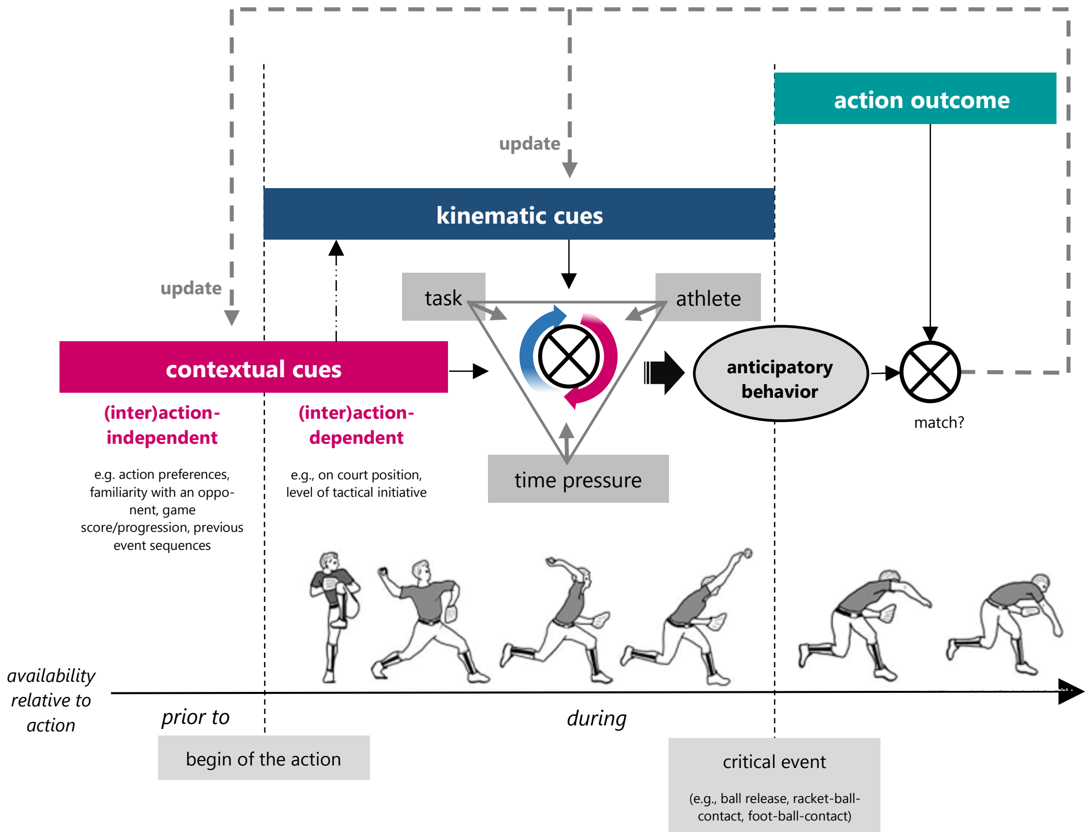


Fig. 10 Temporal availability and interaction of different information sources in the anticipation process.

When the temporal availability of certain information sources is considered in relation to information from the opponent's movements, one can distinguish between *action-*

independent and *action-dependent* cues. In light of this, it has been suggested that athletes can be aware of certain event probabilities at the very early stages of a game, or before the game has even started (e.g., a cross-court shot in tennis occurring generally with higher frequency than a longline shot). Additionally, they might be familiar with their opponent and their strengths, weaknesses and preferences. Later during the game, further information becomes apparent, such as game score or the outcome of previous events, which may influence expectations before the actual action becomes visible. Other cues occur rather late, which means shortly before or parallel to the evolvement of the opponent's kinematics. These are for example the level of tactical initiative or the on-court position. As such cues are directly linked to the opponent's kinematics (e.g., a certain on-court position limiting the possible variety in the kinematic execution of a stroke), they are classified as *action-dependent* contextual cues. During the action, information from the movement of the opponent becomes available for an observer and contextual and kinematic cues are combined to form an expectation which determines the anticipatory behavior of the observer. This process, and the computational rules it follows, are determined by the time pressure, the type of task and the athlete themself (see 2.4.3.1). After the critical event occurs (e.g., ball release, racket-ball-contact or foot-ball-contact), action outcome information becomes available which typically refers to ball flight information in most cases. At that point in time, ball flight information not only serves as the ultimate information source but also gives direct feedback on the athlete's anticipatory performance. Following the comparison of what the observer anticipated and what actually happened, prior information and subjective probabilities that are associated with the outcome of certain events are continuously updated. This idea has been demonstrated in various models of tactical action, in particular the Anticipatory Behavioral Control (ABC) framework by Hoffmann (1993), which was introduced in chapter 2.3. Action preferences of an opponent that an observer was aware of before a game or match for instance (e.g., an opponent in tennis preferring to hit his first serves wide), may be updated during the match, when they show an opposite behavior (e.g., several first serves to the inside of the service box). This way, novel initial conditions for the following anticipatory decisions are repeatedly created.

Rather than differentiating between different sources of a priori information and aligning them in terms of their temporal availability relative to the action, A.M. Williams (2009) proposed four key perceptual skills that have shown to contribute to anticipation judgements (Fig. 11). These perceptual skills include the ability to pick up advance information from the orientation and movement of the opponent (*postural cues*), identify familiarity and structure in sequences of play (*pattern recognition*), gather the visual scene in an efficient manner (*visual search behavior*) and integrate knowledge of likely event probabilities in the prediction process (*situational probabilities*). These skills "interact in a continuous, dynamic and parallel fashion during performance" (p. 74). His framework is based on the notion that the relative importance of these skills may vary based on a range of constraints related to the task, the situation and the performer (cf. Roca & Williams, 2016). As these skills are strongly associated with the use of postural (kinematic) cues and situational probability (contextual cues), the constraints can also be seen as possible determinants, when it comes to the question of when and how different sources of information, such as kinematic and contextual cues, influence anticipatory decisions in the competitive setting.

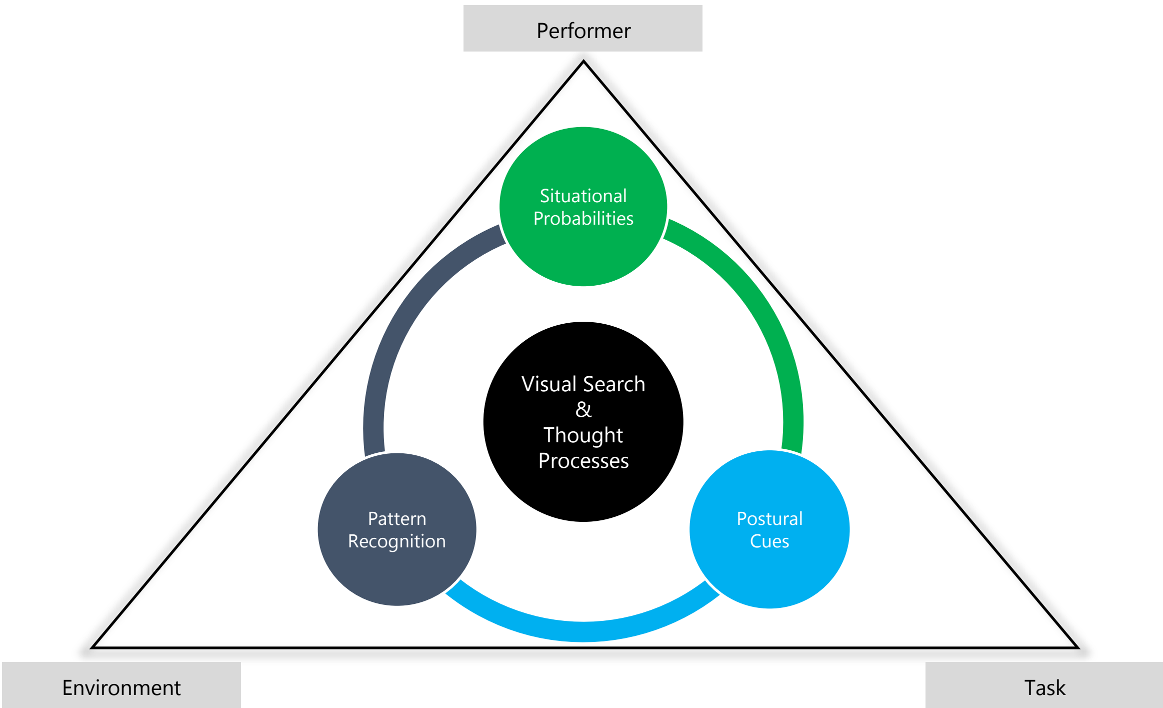


Fig. 11 The interactive relationship between the different perceptual-cognitive skills and processes under various constraints during anticipation and decision making (Roca & Williams, 2016, adapted from Williams, 2009).

2.4.3.1 Possible determinants

There is cumulative experimental evidence to illustrate the relevance of kinematic cues as well as a variety of contextual cues when making anticipatory judgements. However, what still remains an open question is how the information from these different sources is charged with one another in a dynamic and evolving manner to facilitate successful anticipatory performance. A recent call has been made to encourage researchers to work towards a better understanding of this issue (see Cañal-Bruland & Mann, 2015).

While it is plausible that in certain sport situations, athletes may base their anticipation mainly on ball flight information (e.g., when the ball travels a long distance) or information from the opponent's kinematics (e.g., when a tennis player faces the first serve of an unfamiliar opponent at the very beginning of a match and has no prior knowledge about his or her preferences or general event probabilities), in other situations (e.g., at a later point in the same match or during open play) it is likely that they instead rely upon various contextual information, e.g. opponent's shown action preferences, strengths and weaknesses. The relevance of, and reliance on different sources of information in a dynamic sport situation is assumed to be determined by the time pressure exerted on the athlete, the particular task at hand and the athletes themselves.

Time pressure

Time pressure in sport situations obviously varies between different sports and within a sport, as exemplified between fast and slow balls, shots, throws and kicks from various distances (see Tab. 1, p. 21). For example in tennis, a ball hit from the baseline will travel about 25 meters, while this distance will be almost half when a player approaches the net and hits a volley, consequently strongly limiting the time for the other player to make a judgement on where the ball is going to land and to initiate an adequate response movement. Therefore, a slow ball or a ball which travels a long distance would possibly leave an observer with enough time to initiate a response movement at some point when most of the ball flight is already observable – and hence, might make the consideration of other earlier available contextual or postural cues unnecessary. In turn, very fast balls would force an observer to react even before a ball is actually shot or kicked and therefore require the reliance on earlier available cues, which possibly lie outside the opponent's movements. In general, it can be assumed that the earlier a decision has to be made, the higher the contribution of early available action-independent contextual cues and the lower the contribution of later emerging kinematic cues. Amongst others, evidence is delivered by Loffing and Hagemann (2014) who showed that the positioning of an opponent on the field (contextual cue) determines the expectations of an observer, predominantly at early points in time, when little information about an opponent's stroke kinematics are available.

Task

In matters of task constraints, it is likely that the relevance of different information sources when making anticipatory judgements varies, first, among different sports, and second, within a sport in different situations. In tennis (singles) or other racket sports, which represent 1-on-1-situations, the individual preferences, strengths, weaknesses and postural orientation of an opponent may be of most importance. Alternatively, in team ball games, patterns in play or the relative positioning of the players on the field play a more significant role when anticipating opponent's action intentions. Within a specific task (as mentioned above), a performer may rely solely on kinematic cues arising from the opponent's movements, while under more dynamic and severe time pressure situations (e.g., open play), the performer will integrate various information. For example, a tennis player facing the very first serve in a match against an unknown opponent will probably focus on their opponent's movement only, while during a following rally, they might choose to focus on additional information such as the opponent's position on the field or the outcome of the previous shot. It has been argued that the range of perceptual-cognitive skills, and accordingly the integration of different information sources involved in the anticipation process, varies from one situation to the next (cf. Roca & Williams, 2016). Roca, Ford, McRobert, and Williams (2013) attempted to systematically examine how the relative importance of postural cues, pattern recognition and situational probabilities varied across different domain-specific tasks and situations. In their experiment, skilled and less-skilled soccer players were asked to interact as defenders with life-size film sequences of 11-v-11 soccer situations. Participants were presented with two different task conditions in which the ball was either located in the offensive half of the pitch (*far* condition) or in the defensive half of the pitch (*near* condition), and their eye movements, as well as retrospective verbal reports of thinking, were recorded. Superior performance of skilled players was underpinned by differences in task-specific search behaviors and thought processes. In the near condition, skilled players made more statements about the postural orientation of the opponents or teammates, followed by statements related to what their opponents were likely to do in advance of the actual event (i.e., situational probabilities). In the far condition, skilled players made more statements related to the relational information between players (i.e., pattern recognition). The authors suggested that different perceptual-cognitive skills interact during performance, with the relative importance of each varying as a function of the game situation or task presented (cf. Roca et al., 2013). It has been noted that in dynamic sports other than soccer, it is likely that the position of the player(s) on the field/court, as well as the distance between the player and the opponent(s) or the ball, determines the importance and relevance of each perceptual-cognitive skill and accordingly the information sources included in the anticipation process. This is mostly due to the fact that the previously mentioned factors influence the time available for an observer to react (time pressure, see previous section) as well as the costs and benefits associated with accurate and inaccurate judgements (cf. A.M. Williams, 2009).

Athlete

Finally, factors associated with the athlete, such as their individual capabilities and emotional state are assumed to influence how and what information is integrated in the anticipation process. Dicks and his colleagues (2010) revealed that differences in action capabilities (in this case movement speed) affect timing and accuracy in performer's movement response behaviors. In their experiment on soccer goalkeepers, they found that when awaiting penalties, faster goalkeepers, as opposed to slower performers, waited longer till they initiated their response movement. This means that they may rely on later-occurring cues (e.g. kinematic cues), while slower goalkeepers, who must initiate their movement earlier, may be forced to base their decisions on earlier available (contextual) cues. Regarding the emotional state of a performer, Cocks, Jackson, Bishop, and Williams (2015) examined the involvement of high-level (e.g., situational probabilities) and low-level (e.g., postural cues) cognitive processes in anticipation and how their importance interacts with anxiety. Results of their dynamic, time-constrained tennis task indicated that anxiety may have a greater impact on high-level-cognitive processes (the use of contextual cues) rather than the pick-up of low level kinematic information which is potentially due to a shift in attentional control. Similarly, athletes who are fatigued may have to rely on contextual cues in order to anticipate opponent's action intentions since their attention may be focused internally on how best to cope, rather than externally on the movements of their counterparts (cf. A.M. Williams, 2009).

Furthermore, research indicates that the level of expertise plays a significant role, not only regarding the recognition and interpretation of kinematic cues arising from an opponent's movements, but also when it comes to the usage of contextual cues for successful anticipatory performance. While action-independent cues (e.g., preferences of an opponent, game score or previous action outcomes) seem to be used by, and benefit both skilled and less skilled athletes (Barton et al., 2013; Loffing et al., 2015; Paull & Glencross, 1997), action-dependent contextual cues (e.g., players' on-court position) seem to be a salient cue especially for experienced players (Abernethy et al., 2001; Loffing & Hagemann, 2014a). This might be due to the fact that knowledge of task-specific constraints or the like, is necessary to identify varying probabilities associated with action-dependent cues (e.g., an opponent's on-court position in tennis).

2.5 Summary

In many fast-moving sports, such as soccer, tennis, baseball and others, athletes are under enormous time pressure. As ball velocities are very high, the time interval for preparing their own motor responses is very short, making it necessary for athletes to anticipate their opponents' action intentions. As even world-class athletes do not necessarily have faster than average reaction times (e.g., Di Russo, Taddei, Apnile, & Spinelli, 2006), their superior performance cannot be attributed to just physiological, technical or tactical components, but also – and above all – the ability to make better predictions about an opponent's kick, shot, throw or movement direction. When anticipating an opponent's action intentions in time-constrained sport situations, athletes rely on both kinematic cues from the evolving movement of their counterparts and cues that lie outside the action, namely contextual cues. Previous research on anticipation in sports has primarily focused on examining the role of kinematic cues. Studies using classic methodological approaches such as the temporal and spatial occlusion paradigm or eye-tracking technologies, have repeatedly shown that: (1) experts are able to make better and earlier predictions towards their opponent's action intentions; (2) that expert-novice differences are especially apparent at very early points of an opponent's movement evolvement; and (3) that skilled athletes use more efficient visual search strategies, gathering more valuable information from relevant body parts of their opponents. In one of the more prolific divisions of research examining anticipation in sports, the contribution of contextual cues to successful anticipatory performance has been vastly neglected. However, in the past years, there is an increasing interest in examining the role of discrete contextual information sources, such as an opponent's position on the field (Loffing & Hagemann, 2014a), their action preferences (D. L. Mann et al., 2014; Navia et al., 2013), strategic game information, such as game score (Paull & Glencross, 1997), the level of tactical initiative (Crognier & Féry, 2005) and further relevant cues outside the opponent's movements. A promising approach to examine the role of contextual information appears to be the manipulation of context-specific information, while at the same time, keeping kinematic information constant (Loffing et al., 2015). The interaction and the computational rules behind the concurrence of various sources of information in the anticipation process is not yet fully understood, however, three main determinants are assumed to play a major role in this regard, of which include: the time pressure, the task, and the athletes themselves.

Among others, the outcome of previous events and particularly, the pattern of event sequences, were assumed to influence expectations. Initial research findings indicate that they may depict a salient contextual cue in the anticipation process (e.g., Gray, 2002; Misirlisoy & Haggard, 2014), even in the presence of an opponent's movement kinematics (Loffing et al., 2015). I order to understand why event sequences influence our expectations both in general and in a sports context, the following chapter addresses the theoretical background of sequence judgements. To lead over to the research questions addressed in the empirical part of this work, chapter four will focus on the effect of event sequences on visual anticipation in sport.

3 EVENT SEQUENCES

"Prediction is very difficult, especially if it's about the future."

- Niels Bohr (1885-1962)

When making predictions about the future or future events, we often rely on the outcome of previous events and experiences. For example, if our favorite soccer team is playing a team they have beaten in the past two games this season, we are more likely to be confident that they will succeed in the upcoming game. However, if they only won one game and lost the other, we would likely be less confident about their ability to secure another victory. Correspondingly, our expectations towards the outcome of a game, whether it be soccer, football, tennis or another competitive sport, may be influenced based on the availability and presentation of head-to-head statistics. In this regard, not only the overall comparison between two counterparts is crucial but rather the sequence in past event outcomes. Let us assume FC Bayern Munich played Borussia Dortmund six times and we sustained the following sequence of wins (W) and losses (L): WLWLWL. If instead, the sequence presented as LLLWWW, Bayern Munich would still have won half of the games. However, as they won the past three games, supporters are likely to feel more confident about a Bayern Munich win in the upcoming game. Both spectators and actors in sport situations are susceptible to falling for sequential effects when anticipating an opponent's actions or when making decisions in time-constrained situations. For example, when studying penalty shootouts in soccer, Misirlisoy and Haggard (2014) found that goalkeepers displayed a clear sequential bias. Following repeated kicks in the same direction, they become increasingly likely to dive in the opposite direction of the next kick. In response to this paper, Braun and Schmidt (2015) argued that by applying a more appropriate test, no statistical evidence for such an effect could be found in Misirlisoy and Haggard's original data, extended data or in data from an idealized laboratory experiment. However, a goalkeeper's tendency to dive into the opposite direction of the last kick was present in all datasets, leading to the simple message for kickers to "always shoot in the same direction as the previous kicker of your team did" (Braun & Schmidt, 2015, p. 598).

In penalty shoot-outs, as in many other sport situations, the ball often approaches too quickly to react to its direction of motion; instead, athletes must guess the likely direction and initiate a response movement in anticipation. In this context, the outcome of previous events, and more precisely the event sequence, may be a salient *contextual cue* (see chapter 2.4.2). However, the reliance on a previous outcome is subject to misbelief regarding the structure of, or patterns in, event sequences.

In order to provide a comprehensive theoretical background the first part of this chapter will highlight and summarize current research relating to the judgement of (binary) event sequences with an emphasis placed on the associated misperceptions and misbeliefs. The second part will focus on sport performance sequences, and focus particularly on how event history may affect anticipatory decisions in time-constrained sport situations. Following these two sections, the main content of this chapter will be summarized and further consideration will be made in view of the subsequent development of the research questions.

3.1 Judging sequences of binary events

Sequences of events like sport competitions are often seen as a series of wins and losses, which means they are perceived as so called “binary” sequences occurring over time. A binary event (from late Latin binarius, from bini 'two together’; Binary, 2010) is an event that only has two possible outcomes. For example the toss of a coin is a binary event, as it can only result in heads or tails (further examples are the weather forecast, which is expressed as a sequence of sunny or rainy days, the stock market’s performance as a series of ups and downs, and births of single families, which are seen as a sequence of boys and girls; Oskarsson et al., 2009). It is no wonder that when people observe events in the world, they often perceive them as binary sequences occurring over time (Oskarsson et al., 2009). Moreover, when people make predictions about future events, they knowingly or unintentionally incorporate the sequence of past events. “Thinking about the relationships between events and the structure of sequences is a central capacity underlying human adaptive behavior” (Oskarsson et al., 2009, p. 262). For instance, if the firstborn child in a particular family has been a boy for a number of successive generations, one might expect this pattern to continue despite biological birth processes being seen as events produced by random mechanisms (McClelland & Hackenberg, 1978). Likewise, during penalty shoot-outs, soccer goal-keepers demonstrate a tendency to expect a kick to the opposite side after repeated kicks in the same direction, when in reality, it has been observed that kickers generate a rather random sequence of kicks to the left and right (Misirlisoy & Haggard, 2014). The ability to make decisions or judgments on the basis of patterns in previous event outcomes is partly automatic (Oskarsson et al., 2009). For example 2-month-old infants make anticipatory eye movements after being exposed to alternating visual stimuli for a few minutes (Canfield & Haith, 1991) and adults show activity in the prefrontal cortex when viewing a stimulus that interrupts a sequence pattern, indicating that they unconsciously expected a sequence pattern to continue (Huettel et al., 2002).

Primarily, two different types of sequences and their relative perceptions have been the main focus of research in the discipline of behavioral science. Firstly, random sequences, such as coin tosses, roulette wheels, throws of a die, etc. have been the subject of various studies of judgement regarding event sequences (for reviews see Ayton, Hunt, & Wright, 1989; Bar-Hillel & Wagenaar, 1991; Nickerson, 2002). Commonly, a sequence of an event is called random when the events occur independently from another. Secondly, many studies examine nonrandom sequences, mainly sequences occurring in popular sports events, and how these sequences are perceived by people (for reviews see Alter & Oppenheimer, 2006; Bar-Eli, Avugos, & Raab, 2006). Sequences of events are considered non-random, when the events do not occur by chance, e.g., the victory of a sports team is not a random event but rather the result of various factors such as composition of the team, motivation, form of the day, etc.

3.1.1 Random sequences

> "The concept of randomness is encountered frequently in mathematics and the sciences. It is fundamental to probability theory and to quantum mechanics as well as to theoretical accounts of many biological and social systems and phenomena. In psychology, it figures prominently in experimental design and is basic to many widely used statistical methods of data interpretation and hypothesis testing. It is also an important concept in everyday reasoning." (Nickerson, 2002, p. 330)

Defining the term random or randomness has been shown to raise some problems within the current literature (Nickerson, 2002). When asked the question of how to define randomness in digit strings, Ford (as cited in Nickerson, 2002) states that it is “one of the deepest questions in all of probability theory” (p. 330). According to the dictionary, if something is ‘random’, it means that it is “made, done, or happening without method or conscious decision” (Englisch Oxford Living Dictionaries). A sequence of events is called random if the events are causally and statistically independent from another and the sequence is generated by a mechanical or biological device (Oskarsson et al., 2009). A random sequence can be modeled as a series of Bernoulli independent and identically distributed (in the following i.i.d.) trials (Feller, 1950). Correspondingly, Wagenaar (as cited in Burns & Corpus, 2004) states that there are three features of a sequence, which dictate whether or not it can be considered as random. First, there is a fixed set of alternatives (e.g., heads and tails for a fair coin toss). Second, the sequence is generated in a way that it does not consider previous outcomes, which means the events are independent. Third, there is no preference for either of the possible outcomes, so the events are equiprobable (e.g., there is a 50% probability for heads as well as tails for a fair coin toss).

The structure of a sequence of Bernoulli trials is described by various, useful statistics (Oskarsson et al., 2009). One of these is the *probability of alternation*[7], which will be acutely described at this point, as it will be a recurring topic in this chapter. The probability of alternation $p(A) = (r-1) / (n-1)$, for sequences of length n and with the number of runs (i.e., streaks or unbroken subsequences of a single outcome) equal to r indicates the degree of alternation of a given sequence (Oskarsson et al., 2009, p. 263). The term *alternation rate* is used simultaneously, colloquially meaning how often outcome A switches to outcome B and vice versa in a binary sequence. Let us assume we tossed a fair coin 7 times and sustained the following sequence of heads (H) and tails (T): HHTHTTT. The probability of alternation for this sequence (with $n = 7$ and $r = 4$) is consequently $p(A) = (4-1) / (7-1) = .5$, which is in a line with a i.i.d. Bernoulli process, “because we know that the $p(A)$ of a Bernoulli sequence should be close to .5 when the binary outcomes are equiprobable” (Oskarsson et al., 2009, p. 263).

[7] The *probability of alternation* highly correlates with other useful statistics that describe the sequence of Bernoulli trials such as *base rate* or *average run length* (Oskarsson et al., 2009).

Typical examples of mechanisms that illustrate the concept of randomness are a series of fair coin tosses, roulette wheels, throws of a die, balls drawn from urns and also birth sex.

3.1.1.1 Production of random sequences

In his book about probability theory, Reichenbach (1949) suggested that mathematically naive subjects would be unable to produce a random series from a limited number of alternatives. In various studies in which people have been asked to generate random sequences (e.g., Bakan, 1960; Neuringer, 1986; Rapoport & Budescu, 1992, 1997; Treisman & Faulkner, 1990), Reichenbach's suggestion has been experimentally explored and largely verified.

An illustrative example of a so-called *production task* (Bar-Hillel & Wagenaar, 1991) is the study by Bakan (1960) who asked participants "to produce a series of 'heads' and 'tails' such as they might expect to occur if an unbiased coin were tossed in an unbiased manner for a total of 300 independent tosses" (p. 128). Similarly Neuringer (1986) conducted two simple experiments in which participants were asked to generate random sequences of two numbers on the keyboard of a computer terminal. Participants generated sequences that differed significantly from random. However, based on their research findings the author suggested that random-like behavior can be learned. Correspondingly, Rapoport and Budescu (1992) asked subjects to simulate the random outcome of tossing a fair coin 150 times in succession and found that people struggle with producing random sequences. Yet, under adjusted experimental conditions when subjects were asked to generate responses in a strictly competitive game, the deviations from the expectations, derived from a Bernoulli sequence, were considerably and significantly reduced. Treisman and Faulkner (1990) also discovered that when asked to successively speak out numbers between 0-9 in a random manner whenever a visual and auditive signal appeared, some responses were preferred and the preferences varied between individuals. Further experiments that focused on the production of random sequences and investigate subjective randomness by other paradigms were extensively summarized and reviewed by Tune (1964), Wagenaar (1972) and Bar-Hillel and Wagenaar (1991). In summary, they deliver broad evidence that human attempts to produce random sequences or "act randomly" are generally poor. This is likely due to incorrect assumptions about random sampling or the belief in folk theories about luck and randomness (cf. Oskarsson et al., 2009), which is also reflected in the judgement of random sequences.

3.1.1.2 Judgement of random sequences

Aside from the aforementioned experiments in which people have been asked to generate random sequences (e.g., Bakan, 1960; Neuringer, 1986; Rapoport & Budescu, 1992; Treisman & Faulkner, 1990), there is a large body of research on how people judge sequences. Summarized by Oskarsson et al. (2009), participants were asked to detect whether a given sequence was produced by a random or nonrandom process (Falk, 1975, 1981; Lopes & Oden, 1987), to predict future outcomes given some sequence of past events (e.g., Ayton & Fischer, 2004; Gronchi & Sloman, 2008; Matthews & Sanders, 1984), and to assign subjective probabilities to future outcomes (Kahneman & Tversky, 1972; McClelland & Hackenberg, 1978). In the experiment of Lopes and Oden (1987), subjects were asked to judge whether a binary string had been generated by a random or nonrandom process, of which half the presented strings were generated by a Bernoulli process. The nonrandom strings were generated by either a repetition-biased process, so there was a higher degree of streakiness compared to the random generator, or by an alternation-biased process with a higher degree of alternations. The data showed that participants equated long runs and symmetrical patterns (e.g., cyclic or mirror patterns) with non-randomness and classified sequences with many alternations as random. In one of their experiments, Ayton and Fischer (2004) came to a similar conclusion. They presented subjects with varied sequences that differed in their alternation rate and asked them to assign them to either a chance performance process (e.g., successive tosses of a coin) or a human skilled performance (e.g., a professional basketball player's scoring attempts during a game). Consistent with the findings of Lopes and Oden (1987), subjects attributed sequences with low rates of alternation (i.e., more streaks) to human skilled performance. Additionally, counterintuitive sequences with an alternation rate of .5 were attributed to human skilled performance rather than chance performance processes. Further research on perceived randomness (e.g., Gilovich, Vallone, & Tversky, 1985; Lopes & Oden, 1987) also shows that alternation rates of .5 are not judged as random and that people perceive sequences with an alternation rate of .6 as most random (Falk & Konold, 1997).

In addition to most of the subjective randomness tasks, which require bottom-up, sequence-driven judgements (e.g., “Is this sequence random?”), there are a multitude of experiments in which subjects have been asked to make top-down judgements. In this scenario, they have to predict the next event in a sequence given information about how the sequence was generated (Oskarsson et al., 2009). In an early study, Matthews and Sanders (1984) presented subjects with the win and loss records of either football teams or persons betting on coin tosses. They were asked to predict how likely it would be that the next game or toss would result in a win. The authors found that for sport performance sequences, predictions were directly related to previous wins whereas for coin tosses predictions, predictions were inversely related to previous wins. In a similar experiment, Gronchi and Sloman (2008) assigned participants randomly to either a random or nonrandom condition in which they had to predict the outcome of a dice roll after a series of successive dice rolls (random) or a basketball shot after a series of successive shots (nonrandom). In addition to the scenario the authors also varied the probability of alternation. Data suggested that when participants are confronted with a streak in the random condition, they tended to believe that the streak would end in comparison to observing the streaky performance of a basketball player where they believed that a streak would continue. These two phenomena are widely known as *gambler's fallacy (or negative recency),* and *hot-hand belief (or positive recency)*, respectively and will be discussed in detail in the next section. In addition to this study, other research has consistently shown that the beliefs people have about the specific generating mechanism of a given sequence strongly influence their judgements of sequences and whether they show a negative or positive recency (e.g., Boynton, 2003; Kahneman & Tversky, 1972). Moreover, people can simultaneously show a negative and positive recency, even for the same sequence of events (Ayton & Fischer, 2004). In accordance with prior findings, Ayton and Fischer (2004) found that when predicting the next outcome in a random series, subjects show negative recency (the belief that a streak of the same outcome will end). In their experiment they asked subjects to predict the color outcome of a simplified roulette wheel. Results showed that the longer the run of a particular color, the less likely subjects were to predict that color the next time.

However, they also measured subjects' confidence in the success of each prediction (win/loss). Even though the sequence of the color and the win/loss sequence were statistically identical (each binary random processes with a probability of .5 for each event), they found a positive recency effect in subjects' expectations of success and failure. In a third type of study, subjects were asked to assign subjective probabilities to future outcomes. Here, it was repeatedly shown that subjective probability for an event was determined by the features of the process by which it is generated (e.g., Kahneman & Tversky, 1972). McClelland and Hackenberg (1978) assessed subjective probability for sex of next birth. They found that people incorrectly believe that a relationship exists between a family's current sex composition and the probabilities for sex of next birth. They classified subjective probability errors into two types: one being the belief that the prevalent sex in a family is less likely on the next birth, (*gambler's fallacy*) and second being the opposite belief that the prevalent sex is more likely on the next birth (*hot hand*). As this study demonstrates, of which has become repeatedly evident in the previously summarized studies, a consistent finding is that people misperceive random sequential events. The *gambler's fallacy* and the *hot hand phenomenon* are the most documented exemplars of this misperception.

3.1.1.3 Misperception of random sequences – the "gambler's fallacy"

Through the revision of several research studies in the prior section, it was shown that people's perceptions of randomness are systematically biased, which is an idea that is "somewhat older than experimental psychology" (Ayton & Fischer, 2004, p. 1369). In 1796, Laplace published an "Essai Philosophique sur les Probabilités", in which he was concerned with errors of judgement and even provided a whole chapter on "illusions in the estimations of probabilities". A large body of research leads to the general conclusion that "people do not have a statistically correct concept of random i.i.d. sequences" (Oskarsson et al., 2009, p. 64).

Hahn and Warren (2009) summarize three interrelated aspects of people's misperceptions of randomness, which have been established through decades of research and eluded to in the previous section. First, if there is some irregularity in the order of appearance of events in a sequence, people believe that it is more likely and hence, more random. Second, people believe that a sequence of events is more random when equiprobable events occur equally often. Third, people consider an outcome alternation rate higher than .5 (i.e., chance) to be random. These factors of misperceptions of randomness can be linked to the idea of *gambler's fallacy*, as mentioned previously. Laplace (1951) delivered the first published account for this phenomenon, which is defined as "the belief that, for random events, runs of a particular outcome (e.g., heads on the toss of a coin) will be balanced by a tendency for the opposite outcome (e.g., tails)" (Ayton & Fischer, 2004, p. 1369). In other words, "when evaluating sequences generated by random mechanisms, people believe that streaks of events will be shorter than they are in true Bernoulli binomial sequences" (Oskarsson et al., 2009, p. 262). The existence of the *gambler's fallacy* phenomenon has been well documented (for a review see e.g., Tune, 1964). While the term *gambler's fallacy* implies that the judgements are costly to the observer (Oskarsson et al., 2009), the term *negative recency* has been accepted as a more generalized definition, given that both terms still refer to the belief that a streak of events will end.

The phenomenon can be simply illustrated by considering a repeated toss of a fair coin. The probability for heads or tails is equiprobable (50% for every single toss) and tosses are statistically independent from one to another. Assuming one has thrown four heads in a row, a person subject to the *gambler's fallacy* might believe that the subsequent toss is more likely to be tails, even though the two outcomes are still equiprobable. According to Tversky and Kahneman (1971), the reason for this false belief lies in the representative heuristic, leading to a belief in a "law of small numbers". People erroneously believe that small samples must be representative of the large population so every segment of a random sequence should reflect the true proportion. Hence, streaks of one outcome must eventually even out to be representative (Burns & Corpus, 2004). One of the most famous examples of the *gambler's fallacy* occurred on August 18, 1913 in the Monte Carlo Casino. In a game of roulette, black came up twenty-six times in a row. Gamblers increasingly started betting on red after the ball had fallen in black fifteen times, which had doubled and tripled their stakes, leaving some individuals with losses amounting to millions of francs. It was clearly an extremely uncommon occurrence; however, the sequence of 26 blacks in a row is not more or less likely than any of the other 2^{26} = 67,108,863 possible sequences of 26 reds or blacks (cf. Huff & Geis, 1959, pp. 28-29).

In summary, when people are asked to produce or judge random binary sequences, they behave as when they expect the outcomes to revert quickly towards a 50-50 base. Moreover, they expect that such sequences show higher alternation rates and hence, shorter streaks and fewer symmetries than the actual sequences produced by i.i.d. Bernoulli processes (Oskarsson et al., 2009). As previously described, this phenomenon is called the *gambler's fallacy* and increases with growing length of a streak, "such as that people are virtually certain that a run of 10 heads will be followed by a tail" (Oskarsson et al., 2009, p. 267).

3.1.1.4 The other side of the coin – the "hot hand" phenomenon

While the existence of the *gambler's fallacy* phenomenon has been well documented, the contrary phenomenon, namely the *hot hand* phenomenon, has been described in similar depth and has emerged in a multitude of behavioral studies. Both phenomena are often studied simultaneously (e.g., Ayton & Fischer, 2004; Burns & Corpus, 2004; Sun & Wang, 2010). The *hot hand* phenomenon (also referred to as *positive recency*) describes the occurrence where the result of a streaky performance perpetuates the idea that the continuation of a certain event outcome (e.g., a hit following a hit in basketball free throws) is more likely than the occurrence of the opposite outcome. Accordingly, the *belief* in the *hot hand* phenomenon, describes the belief that runs of success in a series of events will continue, e.g., when a tennis player successfully hits three first serves in a row people believe that his chance of successfully hitting the next serve is higher than when he had failed on the previous three first serves. As the term *hot hand* implies a specific type of streak, namely a continuing sequence of successful performance, the term *positive recency* provides a more general naming of the belief in streaks, which also comprises a possible "cold hand" (e.g., Koeppen & Raab, 2012).

One of the most famous examples of the occurrence of a *hot hand* is reflected in Joe DiMaggio's legendary 56-game streak in Baseball (56 consecutive official games in which he got at least one base hit) - a record in American sport history that has not been broken to this day (Bodley, 2011). In the culture of sports, *Streaks* and *"hotness"* are an important part. A somehow amusing example can be observed in the playoffs of the National Hockey League (NHL), where the length of a player's beard is often seen as superstitiously proportional to the number of playoff wins (Vesper, 2015).

Jarvik (1951) delivered first evidence that people who are asked to predict the next outcome in a series of random binary events, tend to predict the same as the last event, showing a positive recency, quite the contrary to the just elaborately described *gambler's fallacy* (negative recency). However, the phenomenon faded for a sequence longer than two prior events and transformed into the opposite phenomenon (a negative recency), which was shown to intensify for longer runs. Several research studies showed that the type of the presented sequence, or the mechanism by which it was created, determined whether subjects showed a positive or negative recency, when they were asked to predict how a sequence of event outcomes would continue (e.g., Gronchi & Sloman, 2008; Matthews & Sanders, 1984). In addition, subjects assign given sequences with a high alternation rate to random processes (e.g., coin tosses) rather than to human skilled performance (Ayton & Fischer, 2004). Object and origin of research on the *hot hand* phenomenon are predominantly sequences in sport performance (see chapter 3.2). Studies on the *hot hand* phenomenon are also present in other academic fields outside the sport domain, such as economics (e.g., Hendricks, Patel, & Zeckhauser, 1993) or cognitive science (e.g., Gilden & Wilson, 1995). For example in economics, an explanatory approach for economic booms or downturns is based on the *hot hand* phenomenon. However, domains outside of sports will not be elaborated on in this summary, as it would excel the framework of this research which is focused on the sequential effects in sports.

3.1.2 Theories and models of sequence judgements

The question as to why people have different expectations for sequences in different domains (e.g., in gambling vs. in sports performance), and why those expectations sometimes do not adequately reflect reality, is addressed by several theoretical implications (cf. Oskarsson et al., 2009). These implications range from simple and intuitive processes to complex mental models trying to explain how human cognitive systems comprehend and reason through sequences. According to Oskarsson et al. (2009), simple accounts of the judgement process, such as statistical regularities in the sequence, urn model sampling-without-replacement interpretations and heuristic folk theories (e.g., streak-of-luck beliefs)[8] seem insufficient to explain differences between expectations for sequences in different domains and the discrepancy from reality. Therefore, the authors posit the need for a cognitive mental models approach. Based on this approach, in most situations where people make sequence judgements, they rely on previously learned mental models. These are characterized by four perceived properties of the sequence-generating mechanism, namely randomness, intentionality, control and goal complexity (cf. Oskarsson et al., 2009). In matters of randomness, the concept that people have of a random mechanism drives their expectations. Generally, sequences with short runs, negative recency, and a representative base rate are associated with random mechanisms. Next to the concept of randomness, the intentionality of the sequence-generating mechanism strongly determines people's expectations and accounts for differences in expectations towards human (intentional) and automatic (unintentional; e.g., roulette wheel) sequence-generators. Furthermore, the extent to which sequential outcomes are controllable is an assertive factor. In sport performance for example, the skill level of an actor will possibly influence whether we expect a streaky or random behavior, as skilled athletes exert more control over outcomes then less skilled players. Ultimately, the perceived complexity of an agent's goal moderates expectations of sequences. This means, when simple goals are involved in binary sequences, i.e., one outcome is definitely more desirable than the other (e.g., hit vs. miss in basketball free throws), people's expectations deviate from when goals are strategic and contingent (e.g., place a ball on the right or left side of the court in tennis). Oskarsson et al. (2009) argues that "while random mechanisms lead to a tendency toward *gambler's fallacy/negative recency* predictions, more intention, more control, or simpler goals are each associated with a tendency toward *hot hand/positive recency* predictions" (p. 277).

Oskarsson et al. (2009) propose that the hidden Markov model approach for modeling properties of a specific sequence could also describe the mental model that an observer relies on to make judgments of what event will occur next in a sequence. Hidden Markov models, which are often used in linguistics, engineering, physics and biology, provide a probabilistic mechanism that generates events in a sequence (cf. Oskarsson

[8] For a detailed description of these rather simple theories of sequence judgements, please see Oskarsson et al. (2009).

et al., 2009). Figure 10 illustrates a general schema for the hidden Markov process model, in which the relationship between hidden underlying generating states (typically represented as probabilistic Ehrenfest urns) and the sequence of observable events is shown.

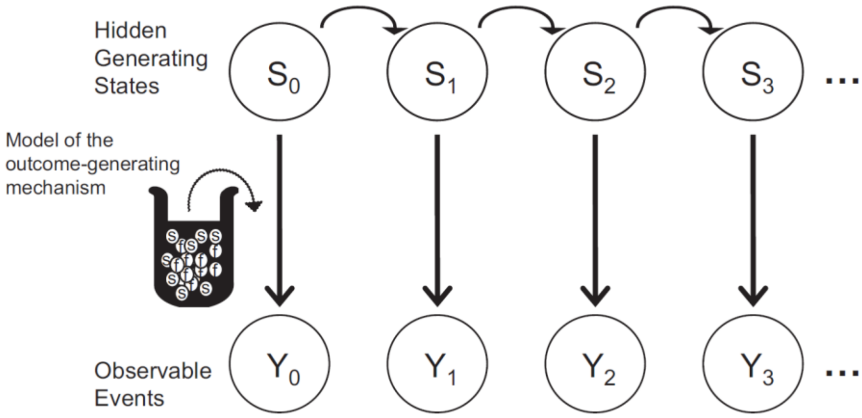


Fig. 12 The general scheme for a hidden Markov process model.

Hidden generating states (S_t) determine observable events (Y_t), where t = [0, 1, 2, 3…], through binary outcome-generating mechanisms represented as probabilistic sampling from urns of outcomes. These urns are usually hypothesized to change composition from hidden generating state to hidden generating state, producing variations in the probabilities (s and f) of the observable event outcomes. S and f indicate success and failure outcomes, respectively. Arrows connecting the hidden generating states (S_t) symbolize the probabilities of changing from one state to another or staying in the same state across time (with time passing from left to right) (cf. Oskarsson et al., 2009).

In Figure 11 a hidden Markov model for a three-state system proposed to represent a basketball fan's judgements of a player's performance, is illustrated. A fan conceives that a player might be in one of three hidden states that determines the level of his or her performance: normal (S_N), hot (S_H) or cold (S_C). A reasonable assumption is that a fan would expect a player to be in a normal state at the beginning of a game and is likely to remain in that state from trial to trial across time (p[remain] = .80). However, there is a possibility that a player will shift into a hot or cold state (p $[shift]_H$ = .10, p $[shift]_C$ = .10), in which he or she is again likely to remain (p[remain] = .80, for S_N, S_H and S_C). Each state is connected to a second process (represented as sampling from an urn) that produces observable responses (hits and misses). In this example, the probability of success (hit) is .85 when in the hot state, .55 when in the normal state, and .25 when in the cold state. It must be noted that while the model of the actual sequence, as an ideal Markov process, will move from one underlying hidden state to the next as a stochastic function of only its current state, a model that mimics the human's judgement of a sequence must consider that humans will infer the new state based on the recent observed events (cf. Oskarsson et al., 2009). In case of the basketball player, a fan will rely on the observed events (e.g., a player hits three in a row) to infer which state he or she is in.

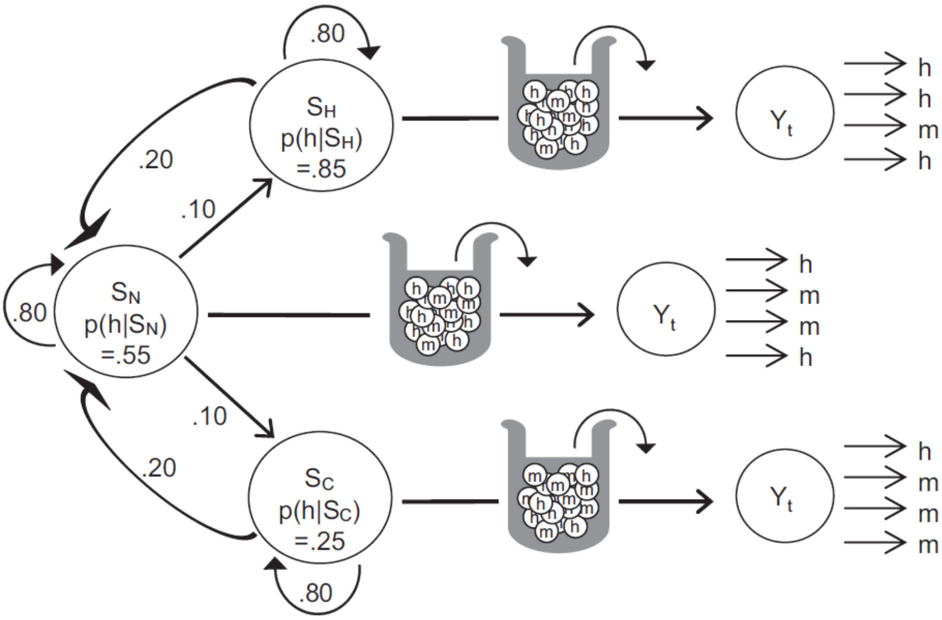


Fig. 13 Hidden Markov model for a three-state system proposed to represent a basketball fan's judgements of player's performance. Circles represent three hidden states (hot, normal, cold) and urns three response-generating mechanisms; Y = observed event, S = state, h = hit, m = miss, t = time (Oskarsson et al., 2009, p. 280).

In summary, the question of why people have different expectations for sequences and why sequences are frequently misperceived, cannot be adequately answered by simple intuitive processes but rather with the help of fairly elaborate mental representations and complex inferences. Oskarsson et al. (2009) propose that the Markov framework not only provides the best statistical modeling of actual sequences but delivers "a useful theoretical notation that provides clear and precise descriptions of the mental models underlying [sequence] judgements" (p.282).

3.2 Sports performance sequences

"When Messi plays at this level he is unstoppable. The second goal speaks for itself."

- Joseph Maria Bartomeu, President of FC Barcelona

The President of FC Barcelona, Joseph Bartomeu (as cited by Güell, 2015), praised Lionel Messi after Barcelona won 3-0 against Bundesliga champions Bayern Munich in the Champions League semifinal in 2015, with Messi scoring two successive goals in the 77th and 80th minute. Like Bartomeu, many players, coaches, commentators and sports fans share the belief that a player can have a *hot hand* and be "unstoppable", "on fire", "in the zone" or "on a roll" (Oskarsson et al., 2009).

The outcome of sport situations or sport events is often seen as a set of binary events occurring over time. For example, the performance of a basketball player during free throw attempts can be described as a series of hits and misses, or the performance of a football team can be described as a series of wins and losses. Therefore, research on the judgment of sport performance sequences is in line with other behavioral studies focusing on binary sequences occurring in games of chance or others. With this in mind, it is not surprising that sports performance sequences are often studied in the same context.

Gilovich et al. (1985), who examined sequences and their perception in basketball shooting, laid the foundation for a multitude of research studies analyzing sequences in sport events and people's perception of these sequences (for reviews see Alter & Oppenheimer, 2006; Bar-Eli et al., 2006). In the previous section, it was highlighted that people's beliefs and judgements differ systematically from actual patterns of random sequences. Furthermore, it has been suggested that there is a difference in how people perceive random sequences (e.g., repeated coin tosses) and sequences produced by humans (Ayton & Fischer, 2004; Gronchi & Sloman, 2008; Matthews & Sanders, 1984). In this section it will become apparent that the deviation between people's beliefs and actual data also applies for sport performance sequences.

As described in the section before and illustrated by the quote of Bartomeu, there is an ongoing belief that athletes or teams can have a *hot hand*, and that streaks of successful performance will continue. However, the actual structures of sport performance sequences do not always reflect people's perceptions of them.

3.2.1 Structure of sports performance sequences

Gilovich et al. (1985) laid the foundation for the *hot hand* research in sports performance. In a seminal study of basketball shooting they examined actual game data and people's perceptions of player's shot sequences. Among other things, they analyzed field goal data of professional basketball players playing for the Philadelphia 76ers and free throw data from the Boston Celtics. They found that both field goal and free throw attempts were largely independent of the outcome of the previous attempts, and furthermore, there was little evidence for unusually long streaks or an unusual number of streaks. However, the survey they conducted in a first step of their research had revealed that basketball players and fans tended to believe that a player's chance of hitting a shot was greater following a hit than following a miss on the previous shot. Researchers came to the same conclusion in a controlled shooting study with intercollegiate basketball teams, which showed that when players were asked to predict their own performance, their beliefs gravitated towards the *hot hand* although their actual performance was contradictory. In accordance to the research findings of Gilovich et al. (1985), no evidence for the existence of a *hot hand* or streaky performance, respectively, could be detected using the data from basketball and baseball game wins (Vergin, 2000), tennis game wins (Richardson, Adler, & Hankes, 1988), baseball hitting (Albright, 1993; Siwoff, Hirdt, & Hirdt, 1988), professional golf (Clark, 2003b, 2004), or volleyball scoring (Miller & Weinberg, 1991).

Vergin (2000) compared actual winning and losing streaks for 28 Major League Baseball teams and 29 National Basketball Association teams to streaks that would have occurred under the assumption that actual game outcome is independent of the outcome of previous games. The results failed to detect any statistically significant differences. For tennis, Richardson et al. (1988) examined whether winning a specific game in a match would predict success in the match but also failed to detect any correlation that would militate in favor of the existence of a *hot hand*. Albright (1993) examined the records of Major League Baseball players through four subsequent seasons to discover whether or not "hot streaks" or "cold streaks", respectively, occur more (or less) frequently than they would by chance. Results suggested that the player's behavior does not differ significantly from what would be expected under a model of randomness and although a certain number of players exhibited definite streakiness in certain years, none of them demonstrated unusually streaky behavior over the entire four-year period. Another study on streakiness in the game of baseball was conducted by Siwoff et al. (1988). Amongst other pieces of interest, they compared batting performance of players in games right after a "hot" or a "cold" streak to the players' overall record. No differences were found for the heightened batting averages following either type of streak. Clark (2003b) investigated the occurrence of streakiness among professional golfers. He analyzed sequence of 'par or better' and 'above par' rounds for players in the 1997 and 1998 Professional Golfers' Association (PGA) Tour and Senior Professional Golfers' Association Senior (SPGA) Tour, showing that the performance of 43% of the players on the latter was streaky. However, they suggested that the observed streakiness in players' scores was due to the difficulty of the golf course rather than to any inherent tendency of players to streak. In a related study, Clark (2004) involved players who played in 1999 on the PGA Tour, the SPGA Tour and the Ladies Professional Golfers' Association (LPGA) tour and examined whether scores in consecutive rounds within tournaments are independent. Apart from the SPGA Tour, for which small, positive correlation was found and presumably due to a greater range of players' skill, correlations between scores on consecutive rounds were negligible. For volleyball, Miller and Weinberg (1991) detected that momentum (defined through situations in which one team came back from three points down to tie) only had minimal, nearly negligible influence on subsequent performance in actual game situations.

In contrast to these reported findings, there is a multitude of research that delivers evidence for streaky performance in other sport domains. For example, Oskarsson et al. (2009) refer to studies in golf-putting (Gilden & Wilson, 1995), darts (Gilden & Wilson, 1995), bowling (Dorsey-Palmateer & Smith, 2004), billiards (Adams, 1995), horseshoes (Smith, 2003), tennis (Klaassen & Magnus, 2001; Silva, Hardy, & Crace, 1988), and hockey goalie performance (Morrison & Schmittlein, 1998). Furthermore, evidence for the existence of a *hot hand* in volleyball was found (Raab, Gula, & Gigerenzer, 2012). In their laboratory based experiments on golf-putting and darts, Gilden and Wilson (1995) were able to demonstrate that subjects did show certain characteristics of streakiness in their performance. Additionally, they found that the probability of the occurrence of streaks was highest when the task difficulty was such that approximately half the trials were successful. Similarly for performance in bowling, Dorsey-Palmateer and Smith (2004) were able to detect evidence of streaky performance as well. Through their research they discovered that the probability of rolling a strike is higher after players have already rolled some number of consecutive strikes, as opposed to after a number of consecutive non-strikes. Furthermore, the difference was shown to intensify with an increasing length of the prior sequence. In contrast to the findings of Richardson et al. (1988) in tennis, Adams (1995) was able to detect a momentum-like phenomenon regarding wins in the game of billiards. In a best-of-21 billiards match, it was shown that a win in the first or the first two games actually resulted in a higher probability of winning the match. Based on a large panel of matches played at Wimbledon in 1952-1992, Klaassen and Magnus (2001) were able to show that points in tennis are neither independent nor identically distributed, and hence, that winning the previous point raises the probability of winning the current point. More than 10 years earlier in an extensive analysis of collegiate tennis data, Silva et al. (1988) postulated that (1) single match outcomes helped to predict subsequent double match outcomes, (2) success in set 1 and set 2 predicted match outcome, and (3) a tie-break win predicted set and match outcome.

When one is having an overall look at the current research examining the actual structure of sport performance sequences, the conjecture that the appearance of sequential dependencies is contingent on the nature of the sports task, seems likely. Oskarsson et al. (2009) remarked that nonrandom sequential dependencies in performances are more likely shown in non-reactive and uniform-trial sports (e.g., darts, golf-putting, basketball free throws, etc.) than in more reactive and chaotic team sports (e.g., basketball game wins, etc.). This speculation, which was similarly proposed by Bar-Eli et al. (2006), could explain the differences between the results of studies on golf-putting, bowling or darts performance and the results of studies in team sports, such as baseball and basketball. In sports like darts, each throw resembles another and is carried out pretty much under the same conditions, so athletes are in more control over their actions than in team sports, where actions strongly depend on an opponent's or a teammate's behavior. Interestingly, in sport situations where there is virtually perfect control over the target outcome and in which it is optimal to behave randomly in order to be inscrutable towards an opponent (e.g., right and left placement of tennis serves or shots in penalty shootouts), athletes are actually able to generate sequences that match the ideal of an independent and identically distributed Bernoulli process (Chiappori, Levitt, & Groseclose, 2002; Palacios-Huerta, 2003; Walker & Wooders, 2001). This is especially remarkable as studies reported in section 3.1.1.1 consistently showed that on average, people struggle with producing random sequences. A possible explanation for this finding could be due to the varying level of awareness and task demands that exist when people produced those sequences. In the majority of studies reported in section 3.1.1.1, participants were explicitly asked to produce a random pattern, which had the potential to deteriorate their ability to do so. In sport tasks on the other hand, participants were not explicitly asked to produce a random pattern but rather acted autonomously in order to display a sense of inscrutability towards their opponent, leaving them subject to further influences (e.g., opponent's behavior). Therefore, they may be able to produce random event sequences in a more unconscious manner herein.

3.2.2 Judgement of sports performance sequences

As previously delineated in chapter 3.1.1.2, research studies focusing on judgement of binary events often include randomly generated sequences (e.g., coin tosses) and sports performance sequences that are suspected to be, for the most part, nonrandom. Thereby, the differences in people's beliefs about these two types of sequences are frequently considered in a contrasting manner.

A consistent research finding in this field is that the generating mechanism of a sequence (e.g., coin toss vs. basketball throw) largely influences people's idea of the structure of a sequence and, in addition, how a given sequence will continue. While people attribute high alternation rates, short streaks and fewer symmetries to sequences produced by random processes such as coin tosses, roulette wheels, throws of a die or balls drawn from urns, they contrarily attribute low alternation rates and streaks of success or failure to sports performance sequences. So depending on how random or nonrandom the underlying process-generating events are judged to be, people either bias toward the induction represented by the *gambler's fallacy* or that of the *hot hand* (Burns & Corpus, 2004).

As previously mentioned, Gilovich et al. (1985) was one of the pioneers in the investigation of sports performance sequences and how they are perceived by observers. They showed that the beliefs of people largely differ from the actual reality. While analysis of actual game data showed that there is no correlation between the outcomes of successive shots, observers and players themselves erroneously believe in a *hot hand* and streaky performance. In their first experiment, Gilovich et al. (1985) asked 100 basketball fans to classify sequences of hits and misses as either “chance shooting”, “streak shooting” or “alternate shooting”. The sequences differed in the number of runs and hence, the probability of alternation. As the authors expected, the subjects showed a decreasing tendency to perceive a sequence as streak shooting as probability of alternation increased. However, more interestingly, the sequences judged to be chance shooting had probabilities of alternation of 0.7 or 0.8 rather than 0.5. This finding is in line with previously presented findings on the judgement of sequences clearly produced by random mechanisms, such as coin tosses (see chapter 3.1.1.2). In addition, Gilovich et al. (1985) produced a survey which found that 91% of fans agreed that a player has “a better chance of making a shot after having just made his last two or three shots than he does after having just missed his last two or three shots, clearly demonstrating a belief in the existence of a *hot hand*.

As reported in chapter 3.1.1.2, various studies have suggested that when subjects are faced with a streak generated by a sports performance, they tended to commit the *hot hand fallacy* (Ayton & Fischer, 2004; Gronchi & Sloman, 2008; Matthews & Sanders, 1984). Subjects make qualitatively different assumptions about the representativeness of causally-linked data, such as win/loss records of sports teams, and noncausally-linked data, such as betting on a coin toss and having profoundly different predictions occur as a result of these assumptions (Matthews & Sanders, 1984). Although the norm in sports performance judgments seems to be the over-prediction of runs and streaks (positive recency), there are also studies that deliver evidence for the opposing phenomenon, a negative recency (e.g., Metzger, 1985). While there is a focal disagreement on the nature of the conceptual dimension that drives the differences between expectations in sequences judgements (Oskarsson et al., 2009), it can be assumed that the exhibited skill and intention of the sequence-generating agent are crucial factors determining the judgement of sports performance sequences (Caruso, Waytz, & Epley, 2010) .

In their extensive review, Bar-Eli et al. (2006) summarize the existing empirical research and real data examination, as well as compare studies that provide no support for the existence of a *hot hand* in sports with studies that provide support for the existence. Table 3 corresponds to their table in an abbreviated manner.

Tab. 3 *Summary of empirical research studies and real game data examination, that either provide support or no support for the existence of the hot hand (following Bar-Eli et al., 2006, p. 527-531).*

Studies that provide…			
1. support for the existence of the *hot hand*.		**2. no support for the existence of the *hot hand*.**	
Larkey, Smith, and Kadane (1989)	Basketball	Gilovich et al. (1985)	Basketball
Tversky and Gilovich (1989b) (Reanalysis of Larkey et al.'s data)	Basketball	Siwoff et al. (1988)	Baseball
Forthofer (1991)	Basketball	Tversky and Gilovich (1989a); see also Gilovich et al. (1985)	Basketball
Gilden and Wilson (1995)	Golf; Darts	Tversky and Gilovich (1989b)	Basketball
Stern (1995)	Baseball	Gould (1989)	Baseball
Adams (1995)	Pocket billiards	Adams (1992)	Basketball
Wardrop (1999)	Basketball	Albright (1993)	Baseball
Klaassen and Magnus (2001)	Tennis	Frohlich (1994)	Baseball
Raab (2002)	Volleyball	Vergin (2000)	Baseball; Basketball
Smith (2003)	Horseshoe pitching	Albert and Bennett (2001)	Baseball
Frame, Hughson, and Leach (2003)	Bowling	Clark (2003a)	Golf
Dorsey-Palmateer and Smith (2004)	Bowling	Clark (2003b)	Golf
		Koehler and Conley (2003)	Basketball
		Gula and Raab (2004)	
		Clark (2005)	Golf

The review of Bar-Eli et al. (2006) resulted in a nearly equal number of non-supportive and supportive studies. However, they stated that “when one closely examines the results, demonstrations of *hot hands* per se are rare and often weak, due to various reasons” (p. 526). Some of the limitations which were mentioned include the use of exceptionally different references that use an unrealistic model or questionable data, setting questionable definitions for hotness and coldness, relating streakiness to difficulty of task, combining data of all players as a group, as well as other constraints (Bar-Eli et al., 2006). In summary, they postulate that scientific support for the *hot hand* is “controversial and fairly limited” (Bar-Eli et al., 2006, p. 535). On the contrary, Iso-Ahola and Dotson (2014) argue that the belief that “success breeds success” has strong empirical foundations in various domains of human performance, if nothing else in the context of sports performance. However, they refer to the phenomenon of “psychological momentum”, which is often used synonymously with *hot hand*, but in their opinion is rather a psychological phenomenon than a mere statistical phenomenon. According to them, this psychological momentum is “alive and well” (Iso-Ahola & Dotson, 2015, p. 115). They argue that the empirical evidence against the *hot hand* provided by e.g. Bar-Eli et al. (2006) often fails on two accounts: the underlying theory or the methodology. The study by Gilovich et al. (1985), along with most other basketball studies in this domain, evaluate a performers “hotness” only on the basis of shooting percentage. However, Iso-Ahola and Dotson (2015) claim that a true test of a *hot hand* necessitates a combined score of various performance indicators, including not only shooting percentages but also assists, defensive and offensive rebounds, steals and forced turnovers. Even though Avugos and Bar-Eli (2015) and Iso-Ahola and Dotson (2015) deliver an open verbal exchange as to their opinions about the existence of the *hot hand* or *psychological momentum* phenomenon, both research groups agree that more solid empirical research is required. Moreover, they agree that somehow or other athletes believe in a *hot hand* because they have experienced it. When a player feels “hot”, the amount of confidence in their own abilities increases, leading to a more relaxed and focused state, likely resulting in an improved performance (Bar-Eli et al., 2006). Robert Hooke (1989) expressed this coherence very well:

> “In almost every competitive activity in which I’ve engaged (baseball, basketball, golf, tennis, even duplicate bridge), a little success generates me a feeling of con-

> fidence which, as long as it lasts, makes me do better than usual. Even more obviously, a few failures can destroy this confidence, after which for a while I can't do anything right" (p.35).

3.3 Summary and further considerations

When making predictions about a future event we certainly rely on the outcome of previous events. As humans, we are naturally sensitive towards patterns in (binary) event sequences (e.g., a series of wins and losses of our favorite soccer team), and incorporate the sequence of past events into our own predictions, despite whether these predictions occur consciously or unknowingly. It is assumed that this phenomenon cannot be explained by simple intuitive processes but rather with the help of complex mental models underlying sequences judgments.

Two of the largest parts of existing research reflecting sequences of events refer to those which are, on one hand, generated by clearly random processes (e.g., coin tosses), and on the other hand, sports performance sequences. Irrespective of the type of sequence generating mechanism one looks at, humans seem to fall victim to their misbeliefs about the structure of, or patterns in event sequences. While the subjective perception of chance, i.e., the *gamblers fallacy*, is a well-known bias relating to the production and judgement of random sequences the structure and judgement of sports performance sequences is mostly examined in the context of an assumed occurrence of the *hot hand* phenomenon. Even though the existence of a *hot hand* in sport performance seems to be controversially discussed, and still requires clarification through further empirical research, it is quite clear that prior event outcomes and patterns in these event sequences influence our expectations towards a subsequent event. This can manifest itself in the expectation that (1) a run of a particular outcome will be balanced by a tendency for the opposite outcome, i.e., the *gambler's fallacy* (e.g., Misirlisoy & Haggard, 2014); (2) a streak of a particular outcome will continue, i.e. the belief in a *hot hand* (e.g., Iso-Ahola & Dotson, 2014); or more generally – (3) the expectation that a certain pattern in event outcomes will continue, irrespective of the nature of this pattern (e.g., Huettel et al., 2002; Loffing et al., 2015). As humans, we actively search for and rely on regularities from temporal sequences of events. We form predictions about upcoming events by identifying patterns in sequences of events, regardless of whether a pattern truly exists or not. Two central aspects pertaining to the perception of patterns of sequences should again be highlighted here, as they may have fallen short in this chapter but are of high relevance for the development of the research questions: Firstly, while the main part of this chapter focused specifically on sequences of identical outcomes (e.g., streaks of wins and losses in gambling or sports performance) it must be noted that the identification of patterns is not limited to repeating patterns, but that alternating or even more complex patterns are identified to predict future events (Canfield & Haith, 1991; Huettel et al., 2002). Huettel et al. (2002), for instance, confronted participants with random binary sequences of images, requiring different button press responses. They examined reaction times as well as brain activity (using functional magnetic resonance imaging, fMRI) of participants viewing a stimulus that interrupted a specific pattern. They found that violation of both, repeating and alternating patterns resulted in increased reaction times as well as prefrontal activation. Furthermore, response times for incongruent stimuli as well as the amplitude of prefrontal activation increased with increasing pattern length. Secondly, the identification of patterns within event sequences is “automatic and obligatory” (Huettel et al., 2002, p. 485) and does not necessarily require the accentuation to a conscious level (as demanded from participants in the studies presented earlier in this chapter). For example, two month old infants were shown to make anticipatory eye movements to the next event when presented with visual stimuli that alternated between the left and right sides of a display (Canfield & Haith, 1991). Furthermore, by three months of age, infants anticipate events within more complex patterns (e.g., left-left-right-left-left-right; Canfield & Haith, 1991).

No matter if conducted in a conscious or unconscious manner, the ability to extract patterns from temporal sequences of events seems to be central to human cognition. As most sequences of events contain a mix of regular patterns and un-patterned, random variability, the process of predicting future events on the basis of temporal sequences is a daily cognitive challenge (cf. Huettel et al., 2002). Additionally, as “behavioral evidence indicates that the identification of patterns within event sequences is automatic and obligatory” (Huettel et al., 2002, p. 485), it is only logical to assume that prior event sequences, and particularly patterns in event sequences, affect anticipation in time constrained sport situations. Most of the studies which focus on event sequences and sequence judgements in sports performance rely on the analysis of existing match data and primarily examine the existence of sequential dependencies or the belief in such, namely the *hot hand* phenomenon (see chapter 3.2 above). They do not look at how prior event sequences and patterns in event sequences affect anticipation in time-constrained situations, despite the proposition that previous event outcomes should be recognized as a relevant contextual cue in matters of anticipatory decisions in sports (see chapter 2.4.2). So far, only a few research studies have adressed this issue and have directily examined the effect of previous events on decision making and anticipation in time-constrained tasks (e.g., Gray, 2002; Loffing et al., 2015).

Although partly introduced in chapter 2.4.2, the following section will discuss empirical evidence on the effect of previous event sequences regarding visual anticipation of action outcomes in sport. The aim of this chapter is to bring together the two components of the theoretical background of this research - anticipation in sports (chapter 2) and event sequences (chapter 3) – in order to form a coherent theoretical framework for the following research questions.

4 THE EFFECT OF PREVIOUS EVENT SEQUENCES ON VISUAL ANTICIPATION OF ACTION OUTCOMES IN SPORTS

Sequences of previous event outcomes bias our expectations towards a future event. This bias may be reflected in a tendency to expect a certain pattern in an event sequence to continue or to be disrupted. Data analysis from penalty shootouts that occurred during the World Cup and Euro cup matches from 1976 to 2012 showed that soccer goalkeepers displayed a clear sequential bias (Misirlisoy & Haggard, 2014). Following repeated penalty kicks in the same direction, it was shown that goalkeepers were more likely to move in the opposite direction for subsequent kick attempts, indicating that they exhibit a *gambler's fallacy*. Braun and Schmidt (2015) argued that by applying a more appropriate test no statistical evidence for such an effect was found in Misirlisoy and Haggard's original data, extended data or data from an idealized laboratory experiment. However, they admit that a goalkeepers' tendency to dive into the direction opposite of the last kick was present in all data sets, speaking in favor of an influence of previous events on anticipation of action outcomes.

Most of the reported studies looking at sequences and sequence judgement in sports performance rely on the analysis of existing match data. Though they partly focus on examining how prior event sequences influence expectations on an upcoming event, they do not primarily look at how prior event sequences affect anticipation in time-constrained situations (except the one from Misirlisoy and Haggard, 2014). However, a few research studies have directily examined the effect of previous events on decision making and anticipation in time-constrained tasks. First evidence was delivered by Gray (2002), who showed that temporal and spatial accuracy of baseball bats was influenced by preceding sequences of pitch speeds. In particular, performance on fast pitches was improved when the pitch followed three consecutive fast pitches, and on the other hand impaired when it followed three slow pitches. Bearing in mind that identical simulations of fast pitches were presented in the trials of interest, the author concluded that "the batters were supplementing the visual information about the current pitch with expectations about speed on the basis of the history of previous pitches"

(Gray, 2002, p. 1143). However, as Gray (2002) rightly acknowledges, only ball flight information was presented, while the pitcher’s kinematics were not visible to the participants. This informaiton may have favoured the participants’ reliance on the previous pitch outcomes and overvalued the relevance of this particular contextual cue. Besides this issue, Loffing et al. (2015) also noted that Gray’s findings only involve trials that are preceeded by identical outcome patterns such as three fast vs. three slow pitches in a row, while neglecting the role of other patterns (e.g., alternating event outcomes). However, research in related fields indicated that humans are not only sensitive to repeating patterns, but those that are alternating or even more complex as well (Huettel et al., 2002). In their study on the role of patterns of previous outcomes on visual anticipation in volleyball, Loffing et al. (2015) sought to adress the above issues. In a video-based experiment, they asked both skilled and novice volleyball players, to anticipate the type of attack (smash vs. lob). Videos were occluded before an attacker made contact with the ball (Exp. 1: 360ms, Exp. 2: 280 ms before hand-ball-contact) and were presented in blocks of six attacks. Within these blocks, attack outcomes in trials 1-4 were manipulated under three conditions (only smashes, only lobs or alternating outcomes) while in trial 5 identical attacks were shown to control for kinematics. Outcomes in trial 5 were either congruent (e.g., a smash after four smashes or a smash after S-L-S-L) or incongruent (e.g., a lob after four smashes, or a lob after S-L-S-L) with the pattern of previous attack outcomes. Prediction accuracy was shown to be higher in congruent target trials when compared to incongruent ones, indicating that participants tended to preferentially expect the continuation of an attack pattern. Additionally, in skilled players, the congruence effect seemed unaffected by the pattern of preceeding attack outcomes suggesting that “phenomena thought to explain such effects (e.g., *gambler's fallacy*; Misirlisoy & Haggard, 2014) may fall short of explaining such effects for different types of patterns” (Loffing et al., 2015, p. 8). Loffing et al. (2015) point to the need to further investigate event history effects on visual anticipation taking into consideration: (1) the inclusion of variable lengths of patterns to dermine their possible impact on the occurrence of sequence effects (Misirlisoy & Haggard, 2014) and (2) a more realistic testing environment that allows for perception-action coupled tasks.

As the findings of Gray (2002) and Loffing et al. (2015) are, to date, rather individual cases of experimental studies examining the direct influence of previous event sequences on anticipation in time-constrained sports tasks, further understanding is warranted. In particular, future research on anticipation in sports should aim to address the following: (1) to verify whether previous event outcomes influence expectations towards an upcoming event, in other words, whether patterns of previous event outcomes are a relevant contextual cue affecting anticipation in the presence of an opponent's movement, and (2) to determine the possible impact of variable length of patters on the occurrence of sequence effects. In the empirical part of this dissertation, I sought to adress these issues.

5 RESEARCH QUESTIONS

The theories and literature referenced throughout the initial portion of this dissertation (Chapter 2) point towards the importance of anticipation in dynamic sport tasks. Furthermore, they assist in the delivery of a comprehensive picture regarding the various information that is used to successfully anticipate opponents' action intentions. It has been highlighted that the utilization of contextual cues, despite being acknowledged as a vital component of anticipation in time-constrained sport situations, has received little attention in comparison to our understanding of kinematic cue usage. In particular, the role of previous event outcomes in this context has been acknowledged as an area in need of further study and evaluation despite earlier research suggesting a potentially meaningful effect of event history on anticipatory behavior.

The goal of this research is to investigate the effect of previous event outcomes on anticipatory behavior through observation of the game of tennis; and through which, to contribute a deeper understanding of the significance of non-kinematic, contextual cues within the anticipation process.

In order to achieve this goal, an extensive analysis of tennis serve direction during real match data from professional tennis matches will first be provided as a means in order to explore the potential link between previous event outcomes and subsequent actions. The research questions which will be investigated through this work include (1) whether choices of serve directions are independent of one another, (2) whether specific patterns in sequences of serve directions occur more or less often than others and (3) whether preceding sequences of serves and patterns in these sequences (combined with the choice of the current serve direction) are associated with varying serve efficiencies and the ultimate result of the rally. The literature comprises several research studies using notational analysis of (tennis) match data (e.g., Hughes & Clarke, 1995; Loffing, Hagemann, & Strauß, 2009), particularly in the context of event sequences (e.g., Klaassen & Magnus, 2001; Palacios-Huerta, 2003; Silva et al., 1988; Walker & Wooders, 2001). As the serve is considered a crucial factor in tennis (Hughes & Bartlett, 2002), differences in serve outcomes have also been the subject of several notational studies (e.g., Furlong, 1995; Hughes & Clarke, 1995; Loffing et al., 2009), investigating the influence of specific factors (e.g., players' handedness, court surface, current score) on serve outcomes. However, to date, no match data analysis has focused solely on the sequence of players' choices of serve directions in a comparable way. In the context of tennis, notational analysis is a form of data analysis which has assisted in improving our understanding of the game through "the process of recording and analyzing the movements made by players during play" (Lees, 2003, p. 713). Therefore, it is through this research that I aim to explore the potential link between previous event outcomes and subsequent actions in tennis in order to develop a fruitful groundwork for future studies in the field.

Following this analysis, the second portion of the research will examine the effect of previous event outcomes, in particular, the patterns in event sequences, on anticipatory behavior in time-constrained sport situations. Notational analysis of real match data derived from the first study may provide valuable insight regarding a potential link between the subsequent serve directions of a player and the event outcomes. However, determining whether previous serve directions directly affect the expectations of a return player regarding the outcome of a subsequent serve, may not be so easily understood using this process. Therefore, this question will be addressed in a second research study. Based on the potential findings of the notational analysis process and on existing research findings regarding the effect of previous event sequences on visual anticipation of action outcomes in sports (see chapter 4; Gray, 2002; Loffing et al., 2015), this study will attempt to use a video-based anticipation task to examine whether patterns in an opponent's previous choices of serve directions affect anticipatory behavior (prediction accuracy and response time) when awaiting a subsequent serve. As findings from related research have identified an effect of sequence length (Huettel et al., 2002), serve-sequences of different lengths will be examined in order to explore if and how the number of an opponent's previous choices of serve directions might moderate a pattern-induced expectation bias in visual anticipation of serve outcomes.

In a third step, this research will be extended to include an examination of the sequences of shots within rallies. While tennis serves depict a somewhat isolated event (comparable to a penalty kick in soccer for example), rallies are the result of an interaction between two players and subsequent shots are directly linked to each other. In a video-based anticipation task similar to the previous one, it will be examined if sequences of a player's choices of subsequent shot directions, and more specifically, the patterns in these choices, influence anticipatory behavior of an opponent within rallies. Again, length of the previous event sequences will be considered as a potential moderating factor.

6 STUDY 1

6.1 Study purpose and hypotheses

The intention of study one was to examine the potential relationship between preceding serves, or sequences of preceding serves, and action outcomes in a subsequent serve. For this purpose, video recordings of professional men's single matches were analyzed. As the serve can be a match-winning factor or at least determine the course of the subsequent rally, it can be hypothesized that servers try to make it as hard as possible for the opposing player to hit a successful, effective return. This strategy, for example, could be reflected in a preference to serve in a particular direction from a specific court side, at a certain point of the serve game, or with the tendency to vary serve directions in a particular manner.

It was assumed that certain "typical" patterns in the sequence of consecutive serves could be identified in the data. Examples of typical patterns might include several successive serves to the same side, alternating serve directions or abrupt direction changes. To this end, the first step in study one was to examine whether the servers' choices of serve direction were serially independent. Moreover, this was an attempt to explore whether specific patterns in sequences of serve directions occurred more or less often than others and if servers followed certain strategies, e.g., switching serve sides on purpose after a particular number of identical serves or alternating serve directions, thereby creating specific patterns in their serve sequences. Additionally, it was critical to examine whether preceding sequences of serves, and patterns in these sequences combined with the selection of the current serve direction, are associated with varying serve efficiencies and the ultimate result of the rally.

Given the exploratory nature of this study on serve sequences in tennis, there was no specific hypothesis identified regarding how the patterns in the serve behavior would look and at what frequency they would occur. This resulted in a variety of indefinite conjectures, concerning the efficiency of certain serve behaviors and therefore, no clear hypotheses could be established. On one hand, it could be argued that servers would be more successful when they switch serve directions at one point, as return players may assume that a server continues serving in a certain pattern (Loffing et al., 2015). On the other hand, athletes might also suffer from a *gambler's fallacy* (Misirlisoy & Haggard, 2014) resulting in higher expectations that an opponent changes his or her behavior and therefore, serving to the same side repeatedly would result in more success. This study sought to shed more light on this issue.

Some general expectations regarding basic study results were postulated: It was expected that servers would direct the majority of their first serves to the outer zones of their opponents' service box (i.e., to the left and right of the return player), and that second serves would result in more balls to the middle of the service box (cf. Loffing et al., 2009). On the first serve, it was postulated that servers would try to hit the ball hard to the corners of the service box in order to impede the return shot of their opponent, as it is harder for a return player to reach the ball properly. Therefore on first serves, it could be assumed that servers would rather take the risk of hitting the ball out, while on second serves they wanted to lower their risk of failure. This meant they hit slightly slower second serves to the central of the service box which additionally limits the angle in which a return player could take advantage of.

6.2 Method

6.2.1 Data Set

The dataset was obtained from videotapes of professional men's single tennis matches. It was comprised of 15 matches between two right-handed players (22 different players were involved) played on hard courts at international Association of Tennis Professionals (ATP) and Grand Slam tournaments in 2014 (e.g., Australian Open, US Open, see Tab. 4). The matches were required to satisfy several criteria in order to be included in the dataset. These criteria included that the players were ranked in the top 80 of the official ATP-ranking by the time of the match and that winning the match was considered important to both players (hence the Grand Slam or ATP tournaments). Furthermore, care was taken to include different types of matches (clear victories and close matches, different match duration).

Tab. 4 *Dataset for study 1. Numbers in brackets refer to the players' ATP-rankings at the time of the tournament.*

Tournament	Rd.	Player 1 / Winner	Player 2	Result
Australian Open	QF	Wawrinka, S. (8)	Djokovic, N. (2)	2:6, 6:4, 6:2, 3:6, 9:7
Australian Open	QF	Berdych, T. (7)	Ferrer, D. (3)	6:1, 6:4, 2:6, 6:4
Australian Open	QF	Federer, R. (6)	Murray, A. (4)	6:3, 6:4, 6:7, 6:3
Apia Int. Sydney	QF	Bernard, T. (52)	Dolgopolov, A. (55)	6:4, 6:3
Apia Int. Sydney	F	Del Potro, J.M. (5)	Tomic, B. (52)	6:3, 6:1
Delray Beach	F	Cilic, M. (29)	Anderson, K. (21)	7:6, 6:7, 6:4
US Open	3	Tsonga, J.-W. (10)	Carreno-Busta, P. (74)	6:4, 6:4, 6:4
US Open	4	Monfils, G. (24)	Dimitrov, G. (8)	7:5, 7:6, 7:5
US Open	4	Nishikori, K. (11)	Raonic, M. (6)	4:6, 7:6, 6:7, 7:5, 6:4
US Open	F	Cilic, M. (16)	Nishikori, K. (11)	6:3, 6:3, 6:3
Sh. Rolex M.	1	Murray, A. (11)	Gabashvili, T. (55)	6:1, 7:5
Sh. Rolex M.	2	Djokovic, N. (1)	Thiem, D. (39)	6:3, 6:4
Sh. Rolex M.	2	Federer, R. (3)	Mayer, L. (25)	7:5, 3:6, 7:6
Sh. Rolex M.	3	Federer, R. (3)	Bautista Agut, R. (18)	6:4, 6:2
Sh. Rolex M.	SF	Federer, R. (3)	Djokovic, N. (1)	6:4, 6:4

Note: F = final, SF = semi-final, QF = quarter-final, 4/3/2/1 = fourth/third/second/first round

The following information was documented for every point in each of the 15 matches:

- general game information (game score, server, serve court),
- direction of the point's first and second serve if applicable (service boxes were divided into three equally spaced zones and balls were assigned to be placed left, central or right from a return player's perspective)
- whether or not it was a valid[9] serve,
- type of serve error if applicable (net; net cord; out),
- server's efficiency (ace[10]; service winner, i.e. when the server wins point and does not have to play another shot; ball in the game; return winner, i.e. when the return player wins the point and does not have to play another shot),
- direction of the previous serve or the sequence of serve directions of two, three or four previous serves (within each service game),
- and whether or not the server ultimately won the point.

[9] A valid serve is one that lands in the boundaries of the serving lines.
[10] An ace is a "serve that is so good that your opponent cannot reach the ball" (Ace, 2005).

6.2.2 Data analysis

Serial dependency of serve directions

The first step in this process was to test each match and player in the data set individually against the hypothesis that the server's choices of serve direction were serially independent. A run-test (e.g., Walker & Wooders, 2001) was conducted and autocorrelations were computed (e.g., Raab et al., 2012).

To this end, for all matches and players individually, choices of subsequent serve directions in first serves were strung together (across all service games). As first serves to the center of the service box were very rare (< 6%), only serves to the right/left of the box were considered.

A Wald-Wolfowitz runs test was conducted for all 15 games and players separately. Additionally, both court sides were also considered individually[11]. For this test, each sequence of consecutive serves to the same side counted as a run. Hence, the more consecutive serves to the right (or to the left) a sequence contains, the fewer runs that can be observed. The observed number of runs is compared with the number of runs according to the player's base rate. The hypothesis of serial independence is rejected if there are too few or too many runs. Too few runs suggests a positive correlation in the player's choices of serve direction: the runs tend to be too short; hence the server is changing direction too often for their choices to be randomly generated. Too many runs suggest that the server's choices are negatively correlated: the runs tend to be too long, thus the server is not changing direction often enough to be consistent with randomness. Using the same criterion as referenced in Gilovich et al. (1985) and Raab et al. (2012), serial dependencies between serve directions are apparent when a player's Z-value is above 1.96 or below -1.96.

Another way to test for serial independence is to compute autocorrelations. Autocorrelation counts the correlation between successive events. In this case, a server's subsequent choices of serve direction. The lag 1 autocorrelation is a correlation between

[11] Because of the players' individual abilities, the choices of serve direction as well as the probability payoffs for a deuce-court point may differ from the choices of serve direction and probabilities for an ad-court point.

the original sequence and the sequence moved by one position (cf.Raab et al., 2012, p. 82). Systematic autocorrelations would indicate that serve directions were serially dependent.

Sequences of successive serves

For every player in each of the 15 matches, relative frequencies of occurrence were calculated for specific sequences of serves comprising two, three, four or five consecutive serves. One sample t-tests were conducted to check whether or not certain sequences occurred more often than chance would predict. With this in mind, several points should be noted: First, only first serves were considered (irrespective of their validity). Second, sequences were provided from consecutive serves within a service game and not overlapping service games. Third, as first serves to the center of the service box were very rare (177 out of 3068), only sequences containing serves to the right/left of the box were considered.

During the course of the data analysis the current serve direction was considered as a function of patterns of previous serves. It was explored, if players rather tended to continue or disrupt a certain pattern that they generated in the previous one, two, three or four preceding serves. For this purpose, serves were either classified as congruent (e.g., a serve to the right after one, two, three or four preceding serves to the right, or a serve to the left after one, two, three or four preceding serves to the left) or incongruent (e.g., a serve to the right after one, two, three or four serves to the left, or a serve to the left after one, two, three or four preceding serves to the right) with a pattern of previous serves. Percentages of congruent and incongruent serves following sequences of one, two, three or four repeated serves to the same direction were calculated across all players. Data of an individual player was only integrated if a specific sequence occurred at least four times in their serve behavior during a certain game. To check for statistically meaningful effects, data was subjected to various t-tests for different sequence lengths separately, to examine whether or not percentage of congruent and incongruent subsequent serves differed. Please note that no RM-ANOVA could be carried out, as the number of subjects that matched the inclusion criteria varied strongly across the different sequence lengths.

Serve efficiency

Regarding the efficiency of serves, percentages of points won by the server were calculated for each court side and serve direction across all players and compared by means of two univariate repeated measures ANOVAs. Furthermore, it was examined whether the percentage of points won by a server varied depending on the sequence of previous serves and the current serve direction, particularly, whether a disruption of a sequence of identical serves resulted in higher win rates than a continuation of a sequence. Therefore, percentages of points won after serves that were either congruent or incongruent with a sequence of identical serves were compared with the help of t-tests for match pairs and separately for sequences of different lengths. Again, data of an individual player was only integrated if a specific sequence occurred at least four times in their serve behavior during a certain game. Please note that the analysis with the help of a RM-ANOVA was impossible, as the number of subjects that matched the inclusion criteria varied between the different sequence lengths.

Serve validity and distribution

For every player in each of the 15 matches, error rates of both the first and second serves were calculated. Subsequently, ball distribution was calculated separately for the deuce and advantage court, and for first and second serves, respectively.

Differences in the players' serving strategies between first and second serves were tested by subjecting the data of mean ball distribution to a series of t-tests for matched pairs (separately for serve direction and court). For example, mean percentage of balls played to the left from the deuce court at first serve was compared to the mean percentage of balls played to the same side from the deuce court at second serve etc.

6.3 Results

6.3.1 Serial dependency of serve directions

Table 5 shows the data and the results of tests for serial independence in the servers' choices of serve direction.

Tab. 5 *Data and results of tests for serial independence in the servers' choices of serve direction.*

Match	Server	Court	Serves R	Serves L	Serves Total	Obs. Runs	Exp. Runs	*Z*	Autocorr. (Lag 1)
14Schanghai	Murray		28	15	43	25	21	1,35	-0,241
	Murray	Deuce	16	7	23	12	11	0,39	-0,189
	Murray	Ad	12	8	20	7	11	-1,49	0,342
	Gabashvili		32	37	69	42	35	1,63	-0,209
	Gabashvili	Deuce	18	16	34	18	18	0,00	-0,033
	Gabashvili	Ad	14	21	35	20	18	0,61	-0,162
14Schanghai	Djokovic		24	28	52	34	27	**2,02**	-0,296
	Djokovic	Deuce	13	16	29	11	15	-1,47	0,257
	Djokovic	Ad	11	12	23	9	12	-1,27	0,256
	Thiem		35	33	68	39	35	0,99	-0,132
	Thiem	Deuce	21	14	35	17	18	-0,11	0,029
	Thiem	Ad	14	19	33	19	17	0,50	-0,139
14Schanghai	Federer		25	28	53	28	27	0,16	-0,041
	Federer	Deuce	15	13	28	9	15	**-2,10**	0,395
	Federer	Ad	10	15	25	10	13	-1,07	0,207
	Bautista Agut		16	43	59	20	24	-1,44	0,159
	Bautista Agut	Deuce	9	20	29	14	13	0,04	-0,093
	Bautista Agut	Ad	7	23	30	13	12	0,40	-0,128
14Schanghai	Federer		29	42	71	35	35	-0,08	-0,011
	Federer	Deuce	16	22	38	16	20	-1,02	0,163
	Federer	Ad	13	20	33	13	17	-1,21	0,192
	Djokovic		40	35	75	29	38	**-2,18**	0,235
	Djokovic	Deuce	22	17	39	19	20	-0,22	0,028
	Djokovic	Ad	18	18	36	21	19	0,51	-0,139
14Schanghai	Federer		50	73	123	59	60	-0,25	0,017
	Federer	Deuce	30	36	66	34	34	0,07	-0,024
	Federer	Ad	23	42	65	27	31	-1,02	0,117
	Mayer		49	53	102	56	52	0,81	-0,09
	Mayer	Deuce	30	27	57	27	29	-0,65	0,069
	Mayer	Ad	23	30	53	32	27	1,40	-0,21
14AUSopen	Djokovic		70	74	144	77	73	0,68	-0,063
	Djokovic	Deuce	35	37	72	27	37	**-2,37**	0,264
	Djokovic	Ad	35	37	72	34	37	-0,71	0,069
	Wawrinka		78	82	160	75	81	-0,94	0,068
	Wawrinka	Deuce	42	46	88	41	45	-0,84	0,079
	Wawrinka	Ad	36	36	72	30	37	-1,66	0,181
14Delray	Anderson		76	55	131	61	65	-0,69	0,054
	Anderson	Deuce	42	31	73	34	37	-0,64	0,061
	Anderson	Ad	43	32	75	43	38	1,26	-0,155

	Cilic		62	45	107	54	53	0,17	-0,026
	Cilic	Deuce	43	24	67	34	32	0,59	-0,089
	Cilic	Ad	28	28	56	29	29	0,00	-0,018
14AUSopen	Ferrer		49	57	106	59	54	1,04	-0,109
	Ferrer	Deuce	24	26	50	34	26	**2,30**	-0,342
	Ferrer	Ad	25	31	56	36	29	**2,00**	-0,283
	Berdych		69	67	136	69	69	0,00	-0,007
	Berdych	Deuce	32	40	72	43	37	1,55	-0,192
	Berdych	Ad	37	27	64	27	32	-1,35	0,156
14AUSopen	Federer		53	62	115	52	58	-1,16	0,099
	Federer	Deuce	35	29	64	26	33	-1,71	0,196
	Federer	Ad	20	38	58	30	27	0,82	-0,127
	Murray		60	81	141	75	70	0,88	-0,079
	Murray	Deuce	35	43	78	37	40	-0,60	0,057
	Murray	Ad	28	42	70	34	35	-0,15	0,002
14Sydney	Del Potro		18	20	38	22	20	0,51	-0,135
	Del Potro	Deuce	9	12	21	12	11	0,10	-0,119
	Del Potro	Ad	9	8	17	11	9	0,52	-0,247
	Tomic		17	28	45	29	22	**2,04**	-0,337
	Tomic	Deuce	13	9	22	11	12	-0,06	-0,066
	Tomic	Ad	4	19	23	8	8	0,00	-0,167
14Schanghai	Dimitrov		50	36	86	40	43	-0,64	0,056
	Dimitrov	Deuce	23	23	46	26	24	0,45	-0,109
	Dimitrov	Ad	27	13	40	22	19	1,08	-0,229
	Monfils		49	46	95	51	48	0,53	-0,064
	Monfils	Deuce	22	28	50	26	26	0,10	-0,035
	Monfils	Ad	27	18	45	25	23	0,60	-0,126
14Sydney	Tomic		25	35	60	25	30	-1,38	0,154
	Tomic	Deuce	19	14	33	15	17	-0,59	0,109
	Tomic	Ad	6	21	27	10	10	0,00	-0,034
	Dolgopolov		33	23	56	31	28	0,81	-0,119
	Dolgopolov	Deuce	23	6	29	9	11	-0,60	0,15
	Dolgopolov	Ad	10	17	27	12	14	-0,46	0,084
14USopen	Tsonga		42	38	80	36	41	-1,11	0,11
	Tsonga	Deuce	22	20	42	24	22	0,48	-0,122
	Tsonga	Ad	20	18	38	18	20	-0,48	0,076
	Carreno-Busta		34	55	89	50	43	1,58	-0,179
	Carreno-Busta	Deuce	27	21	48	31	25	1,74	-0,286
	Carreno-Busta	Ad	7	34	41	15	13	1,08	-0,211
14USopen	Nishikori		59	73	132	61	66	-0,93	0,074
	Nishikori	Deuce	33	39	72	27	37	**-2,33**	0,261
	Nishikori	Ad	26	34	60	27	30	-0,92	0,096

	Raonic		86	92	178	95	90	0,77	-0,063
	Raonic	Deuce	55	38	93	49	46	0,66	-0,084
	Raonic	Ad	31	54	85	38	40	-0,56	0,047
14USopen	Nishikori		35	36	71	35	36	-0,36	0,028
	Nishikori	Deuce	18	19	37	21	19	0,34	-0,107
	Nishikori	Ad	17	17	34	18	18	0,00	-0,029
	Cilic		43	45	88	48	45	0,65	-0,08
	Cilic	Deuce	17	27	44	18	22	-1,08	0,16
	Cilic	Ad	26	18	44	24	22	0,39	-0,105

In four out of 90 cases, players had more runs than expected and in other four cases, players had fewer runs than expected (bolded in Tab. 5). The autocorrelation values (lag 1) for each match and player are also shown in Tab. 5. Autocorrelations around zero (±.1) are found for 40 of 90 of all cases; in the remaining 50 cases, players show significant autocorrelations between .1 and .4, indicating that successive choices of serve directions are dependent on each other. However, only for eight cases, it can be assumed that players' choices of serve direction were dependent on each other according to autocorrelation and the runs test.

6.3.2 Frequency of occurrence of certain serve sequences

Sequences of two consecutive serves: For sequences of two serves, only the sequence RL (M = 26.86%, SD = 4.58%) occurred more often than random chance (25%) would predict, $t(29)$ = 2.224, p =.03, d = .40, 95% CI [0.03, 0.78], while occurrences of sequences RR (M = 22.23%, SD = 7.96%), LR (M = 24.36%, SD = 4.71%) and LL (M = 26.54%, SD = 10.18%) did not deviate significantly from chance.

Sequences of three consecutive serves: For sequences of three serves, occurrence of almost all sequences did not deviate significantly from chance, only sequences LRR (M = 10.70%, SD = 4.25%), $t(29)$ = -2.324, p = .027, d = .42, 95% CI [.04, .79], and LLR (M = 10.09%, SD = 3.54%), $t(29)$ = -3.732, p = .001, d = .68, 95% CI [.28, 1.07], occurred less often than random chance (12.5%) would predict (see Fig. 14A).

Sequences of four consecutive serves: For sequences of four serves, only sequences LRRR (M = 4.14%, SD = 3.78%), $t(29)$ = -3.056, p = .005, d = .56, 95% CI [.17, .94], and LLRR (M = 4.28%, SD = 3.40%), $t(29)$ = -3.178, p = .004, d = .58, 95% CI [.19, .96], occurred less often than random chance (6.25%) would predict (see Fig. 14B).

Sequences of five consecutive serves: For sequences of five serves, sequences RRLLR (M = 1.89%, SD = 3.05%), $t(29) = -2.222$, $p = .034$, $d = .41$, 95% CI [.03, .78], LRRRR (M = 1.79%, SD = 2.49%), $t(29) = -2.934$, $p = .006$, $d = .54$, 95% CI [.15, .92], and LLRRL (M = 1.93%, SD = 2.74%) $t(29) = -2.383$, $p = .024$, $d = .44$, 95% CI [.06, .81], occurred less often than random chance would predict, while all other sequences occurred with nearly equal frequency that did not differ significantly from 3.125% (see Fig. 14C).

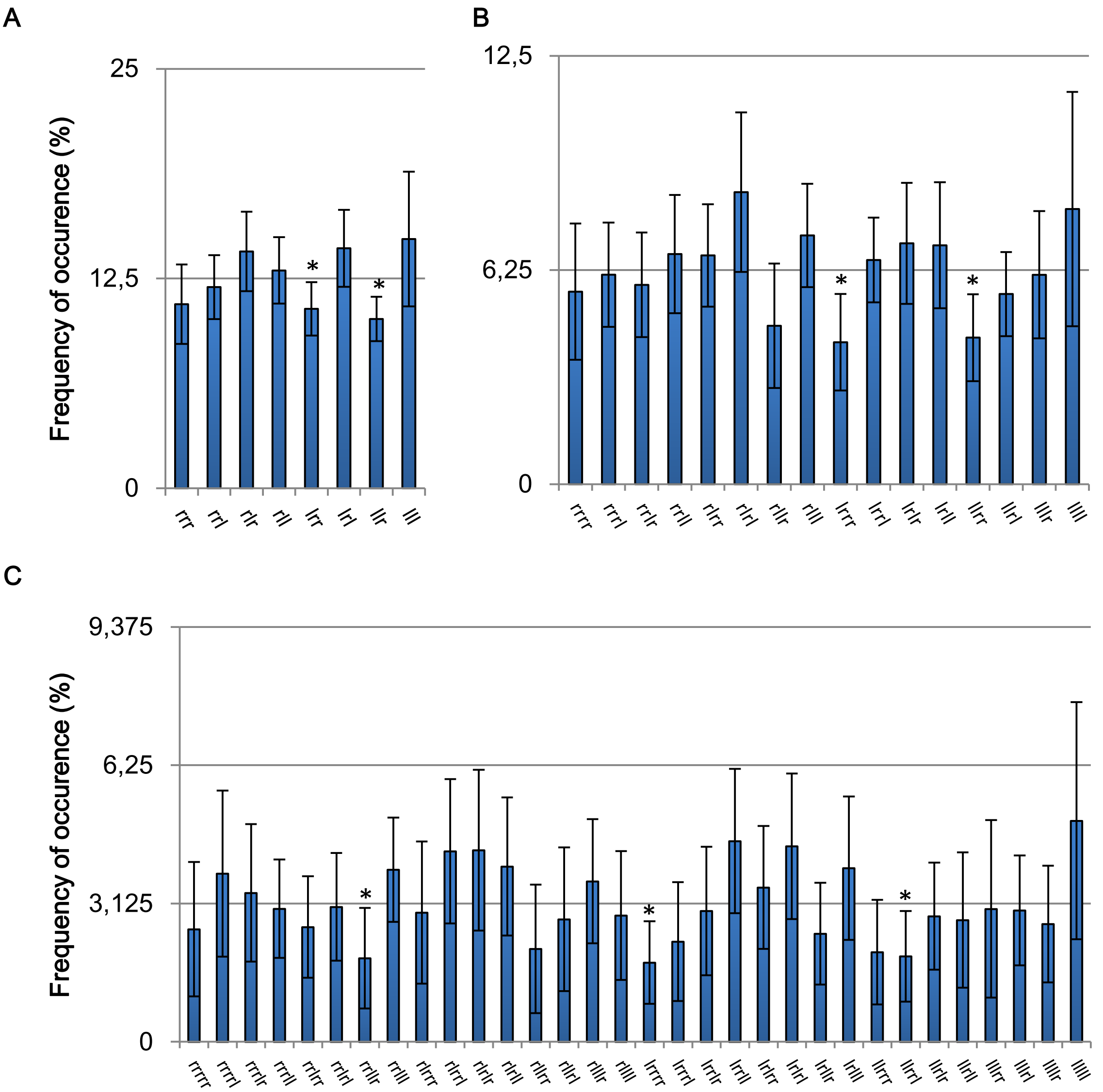


Fig. 14 Mean frequency of occurrence of different sequence types of three (A), four (B) or five (C) consecutive serves across all players and matches. Error bars represent 95%-confidence intervals, * ≙ $p < .05$.

6.3.3 Serve direction as a function of previous serves

For repeated serving to the same side (either to the left or the right of a return player, irrespective of court side), the percentage of subsequent serves directed to the incongruent side (i.e., a serve to the left after one, two, three or four serves to the right or a serve to the right after one, two, three or four serves to the left, respectively) decreased by trend (see Fig. 15). However, only for the pattern RRRR/LLLL, statistically significant differences between the percentage of congruent (*M* = 62.38%, *SD* = 14.08%) and incongruent (*M* = 37.66%, *SD* = 14.08%) subsequent serves were found, $t(13) = 3.292$, $p = .006$, $d_{unb} = 1.66$, 95% CI [0.49, 2.98].

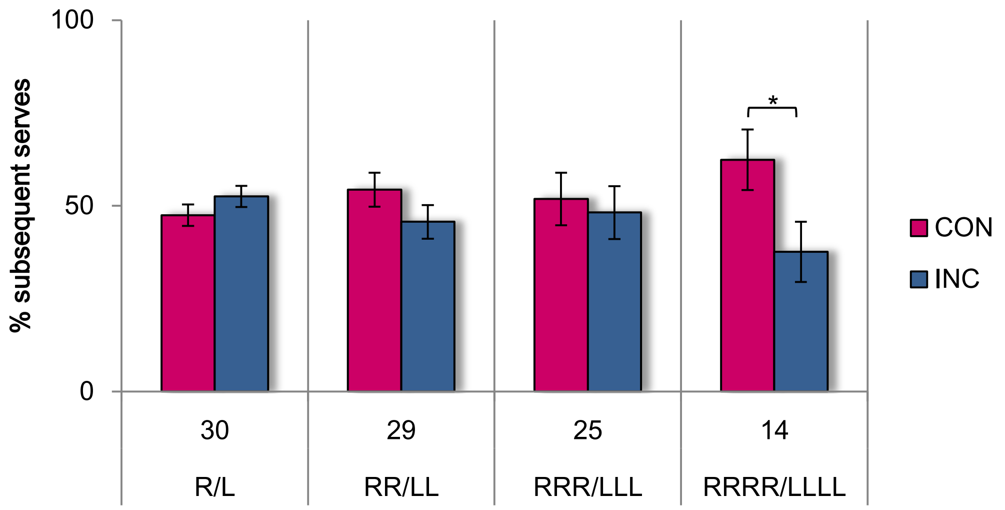


Fig. 15 Percentage of subsequent serves directed to the congruent and incongruent side after one, two, three or four consecutive serves with identical serve direction. Numbers above the sequences refer to the total number of occurrences in the data set. Error bars represent 95%-confidence intervals, * ≙ p < .05.

To gain further insight, additional analyses were carried out for sequences of consecutive identical serves to the left and right, separately. For repeated serving to the right, differences in the percentage of congruent and incongruent subsequent serves could only be revealed for one preceding serve (see Fig. 16A). After one serve to the right, subsequent serves that were incongruent (i.e., to the left, *M* = 55.78%, *SD* = 11.13%) occurred more often than congruent (i.e., to the right, *M* = 44.22%, *SD* = 11.13%) serves, $t(29) = 2.844$, $p = .008$, $d_{unb} = 1.01$, 95% CI [0.27, 1.79]. For repeated serving to the left, the percentage of subsequent serves directed to the congruent (left) side increased (see Fig. 16B). After one serve to the left, in 50.73% (*SD* = 11.96%) of the cases the subsequent serve was directed to the left, while after two serves to the left, 58.39% (*SD* = 13.95%) were directed to the left, after three serves 54.84% (*SD* = 20.89%) were directed to the left and after four serves 71.26% (*SD* = 7.12%) of subsequent serves were directed to the left (congruent side). However, the percentages only differed significantly between congruent and incongruent serves after two preceding serves to the left, $t(26) = 3.127$, $p = .004$, $d_{unb} = 1.17$, 95% CI [0.37, 2.02], and after four consecutive serves to the left, $t(6) = 7.903$, $p < .001$, $d_{unb} = 5.19$.

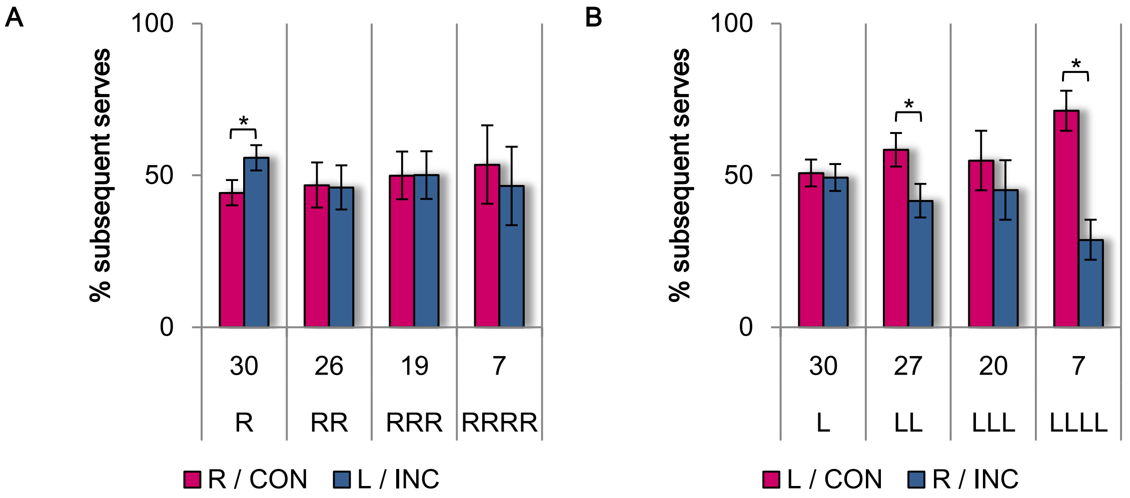


Fig. 16 Percentage of subsequent serves directed to the congruent and incongruent side after one, two, three or four consecutive serves on the right (A) or left (B) side. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Figure 17 shows that when examining the serve direction after sequences of identical serves to the right or left in a combined manner, tennis players tend to serve to the left (to the backhand side of a right-handed opponent) after sequences of identical serves, irrespective of whether the sequences consisted of repeated serves to the right or to the left. In fact, serves to the left occurred more often compared to serves to the right after one, $t(29) = 2.077$, $p = .047$, $d_{unb} = 0.74$, 95% CI [0.01, 1.49], or two preceding serves, $t(28) = 2.980$, $p = .006$, $d_{unb} = 1.08$, 95% CI [0.32, 1.88].

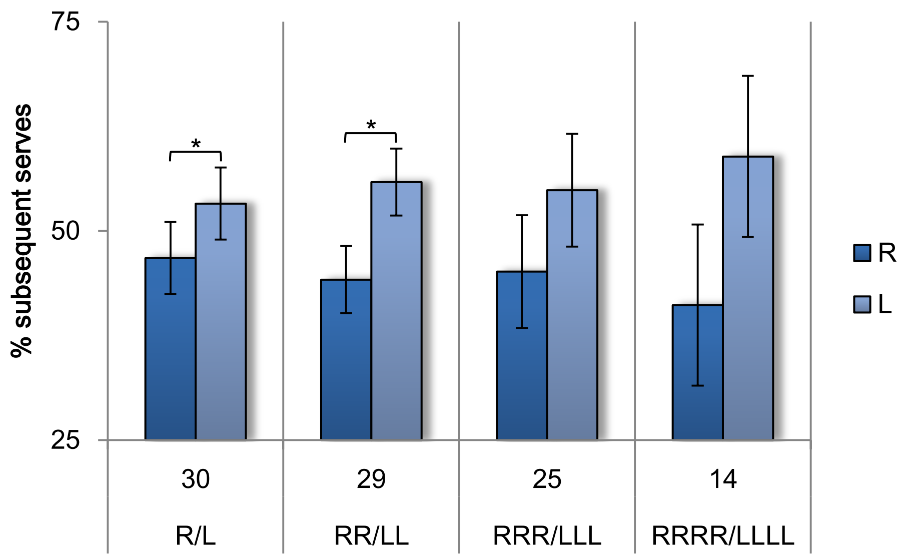


Fig. 17 Percentage of subsequent serves directed to the right or left side after one, two, three or four identical serves. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Given that alternating sequences may (1) depict a clear pattern in an opponent's serve behavior, (2) seem to occur, on average, relatively often during real match data (see Fig. 14), and (3) have recently been studied in experimental research on sequential effects in visual anticipation (Loffing et al., 2015), I additionally considered alternating sequences of different lengths (RL/LR, RLR/LRL and RLRL/LRLR) in this analysis. For sequences of alternating serve directions I defined a subsequent serve as congruent, if it was congruent with the pattern generated by the sequence (e.g., a serve to the right after RL/LRL/RLRL or a serve to the left after LR/RLR/LRLR). Visual inspection of Figure 18 suggests that for sequences of two or three serves with alternating serve direction, subsequent congruent serves occur with higher frequency than incongruent serves while for longer sequences the difference vanishes. However, no statistically significant differences in the percentage of congruent and incongruent serves were found for any of the pattern lengths.

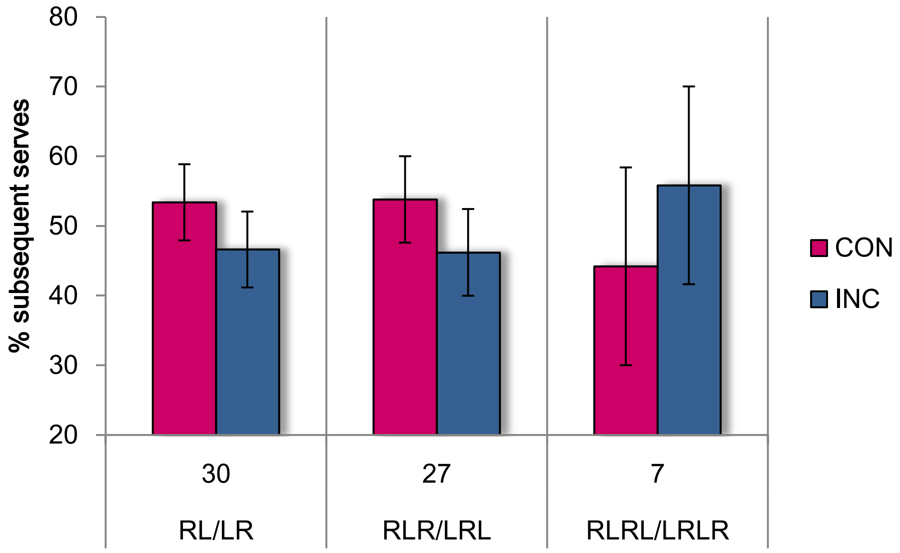


Fig. 18 Percentage of subsequent serves that were either congruent or incongruent with different patterns generated by a preceding sequence of two, three or four consecutive serves. Error bars represent 95%-confidence intervals.

6.3.4 Serve efficiency

Regarding the efficiency of serves measured in points won, overall, servers won points after a valid first serve in 67.55% (*SD* = 7.66%) of all cases. The percentage of points won by a server or a return player after a valid first serve, displayed as a function of court and serve direction, are illustrated in Fig. 19.

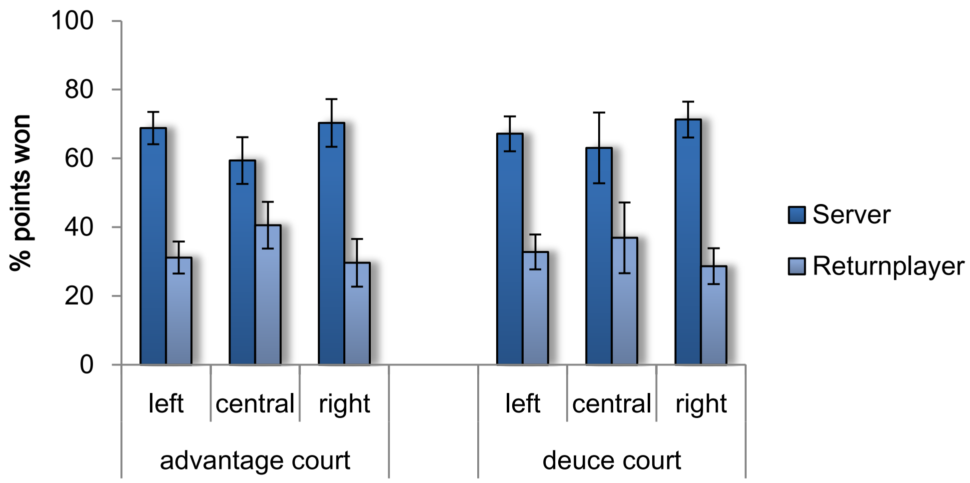


Fig. 19 Percentage of points won by the server or the return player subject to court and serve direction for valid first serves. Error bars represent 95%-confidence intervals.

Two univariate repeated measures ANOVAs were carried out for the court sides separately. For the advantage court, a main effect of serve direction was revealed, $F(2, 58) = 4.145$, $p = .021$, $\eta_p^2 = .125$, while no effect was found for the deuce court . Visual inspection of Fig. 19 and pairwise comparisons (with Bonferroni corrections for pairwise comparisons) suggest that for the advantage court, servers won the point with a higher probability when they were serving to the left (M = 68.83%, SD = 12.48%) as opposed to the central (M = 59.41%, SD = 18.19%), $t(29) = 2.34$, $p = .026$, $d_{unb} = 0.59$, 95% CI [0.07, 1.13], or when they were serving to the right (M = 70.32%, SD = 18.59) as opposed to the central, $t(29)= 2.38$, $p = .024$, $d_{unb} = 0.59$, 95% CI [0.08, 1.10]. No differences in the probability of the server ultimately winning the point due to different serve directions were found for the deuce court.

In the next step, it was examined whether the percentage of points won by the server varied depending on the sequence of serve directions he previously generated and the current serve direction. Overall, it seems that servers were more likely to win the point when they served to the incongruent side (e.g., a serve to the left after a sequence of consecutive serves to the right or a serve to the right after a sequence of serves to the left) and that this effect strengthens with increasing length of a sequence (see Fig. 20). However, statistical differences between congruent and incongruent serves could only be detected after one previous serve, $t(29) = 2.275$, $p = .03$, $d_{unb} = .43$, 95% CI [.04, .84], where servers more often won the point when they served to the incongruent side

(*M* = 74.27%, *SD* = 9.64%) as opposed to the congruent side (*M* = 69.67%, *SD* = 11.04%).

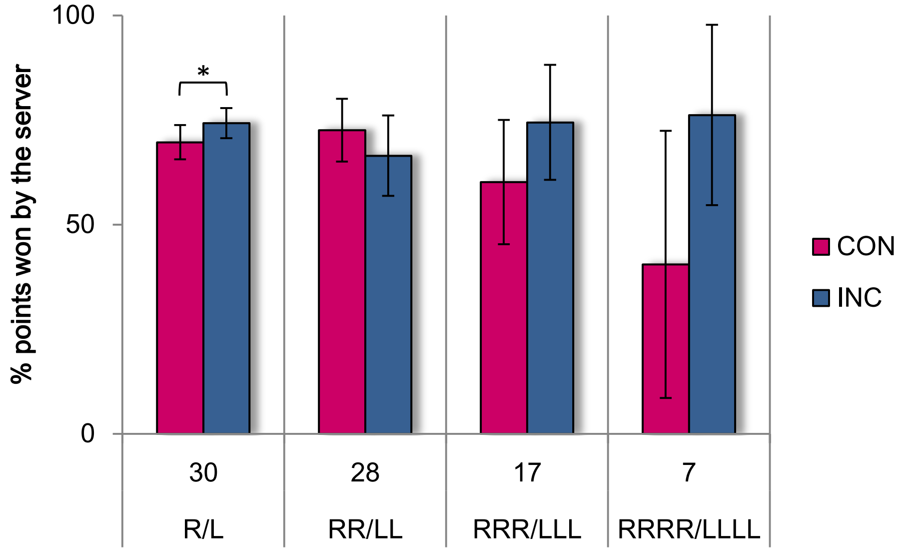


Fig. 20 Percentage of points won by the server for serves that were either congruent or incongruent with preceding sequences of different lengths of identical serves. Error bars represent 95%-confidence intervals, * ≙ $p < .05$.

As the ultimate win of the point may not be an optimal measure of serve efficiency, I additionally examined whether the percentage of serve winners (aces and when the server does not have to play another shot after the serve) and the percentage of return winners (when the return player does not have to play another shot after the return) differs for congruent and incongruent serves after sequences of identical serves of different lengths. However, data revealed no meaningful findings.

6.3.5 Serve validity and serve distribution

Altogether, 4200 serves were analyzed, consisting of 3068 first and 1132 second serves. First serves were valid in 59.65% (*SD* = 7.08%) of all cases, while second serves were valid in 92.41% (*SD* = 6.11%) of all cases.

The ball distributions for first and second serves from the deuce and advantage court are illustrated in Figure 21. The associated inferential statistics are summed up in Table 6.

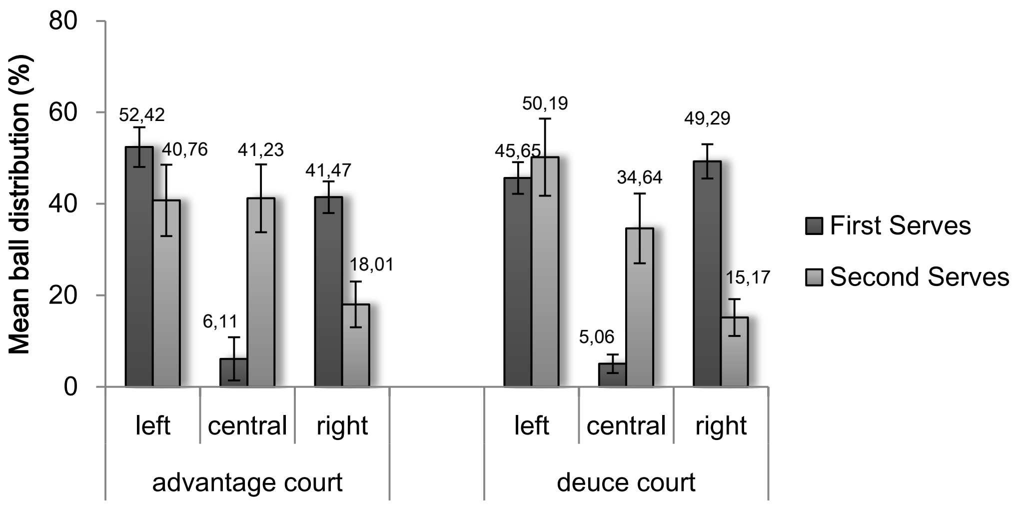


Fig. 21 Mean percentage of ball distribution (error bars represent 95%-confidence intervals) at first and second serves separately for deuce and advantage court.

Mean percentages for ball distribution were different between first and second serves for nearly all serve directions.

Tab. 6 *Comparison of the ball distribution in each direction (left, central, right) as a function of number of serve separately for service box, by means of t-tests for matched pairs (two-tailed).*

Service box	Direction	*df*	*r*	*t*	*p*	*d*	95%-CI
Advantage	Left	29	.18	2.911	.007	.69	[0.19, 1.18]
	Central	29	-.003	-9.344	<.001	-2.41	[-3.21, -1.61]
	Right	29	.04	7.143	<.001	1.80	[1.12, 2.47]
Deuce	Left	29	.05	-1.040	.307	-.26	[-.76, .24]
	Central	29	.13	-7.958	<.001	-1.99	[-2.68. -1.27]
	Right	29	-.09	12.108	<.001	3.26	n.a.

First serves were directed to the right significantly more often from both advantage court and deuce court, compared to second serves. Furthermore, when compared to second serves, first serves were directed to the left from the advantage court significantly more often, which was not applicable for serves to the left from the deuce court. Conversely, second serves were directed to the central for both deuce and advantage court significantly more often when compared to first serves.

6.4 Discussion

In the analysis of 15 professional tennis matches, I found that both measures – runs and autocorrelation – overall, provided only weak evidence for serial dependencies in servers' choices of serve direction. In most of the matches, players' serve directions seem to reflect a randomly generated sequence. In contrast to an earlier study on serial dependencies in servers' choices of serve direction in tennis provided by Walker and Wooders (2001), sequences of serve directions were not only examined separately for the two court-sides (deuce-court and ad-court) but also in a combined matter. I suspected that both server and return player may not perceive sequences of serve directions on the two courts separately, but as a whole. Nonetheless, only in three out of 30 cases did results indicate that players' choices of serve directions were not independent.

Experiments outside the field of sports have repeatedly shown that human attempts to produce random sequences or to 'act randomly' are generally poor. However, in accordance with previous research studies on performance in sports (Chiappori et al., 2002; Palacios-Huerta, 2003; Walker & Wooders, 2001), tennis players seem able to generate sequences of serve directions that match the ideal of an independent and identically distributed Bernoulli process. This can be interpreted as having especially great benefit in situations where it is optimal to behave randomly in order to be as inscrutable as possible towards an opponent. The varying task demands and the associated level of awareness can deliver a possible explanation for the difference in the ability to produce random sequences in both a sports context and in a controlled experiment. In most of the reported studies in section 3.1.1.1, participants were asked to "produce a random pattern". This concrete verbalization of the task has potentially deteriorating effects on their ability to do so as they generally produce sequences with more alternations than expected by chance. In a sport task like serving in tennis, players are not asked to "produce a random pattern" but rather try to be as inscrutable as possible towards an opponent (by producing a random pattern). Additionally they are subject to further influences (e.g., opponent's behavior) at once. It can be assumed that in such a situation, players may be able to produce random event sequences, more or less, unconsciously.

It must be noted that this type of data analysis has a clear limitation. Serve directions in first serves were strung together for each player and each match (and each court side) and a continuity was assumed. However, in real matches, the players' serve directions occur in sections of approximately 4 - 10 serves, being interrupted by the service game of the opponent. Therefore, frequencies of occurrence of specific serve sequences, as well as conditional probabilities, were additionally computed while taking this aspect into account. Here, only sequences of serve directions that occurred within single service games were considered.

The frequency of certain serve sequences of different lengths underlines the previous reported findings following the run-test and the test for autocorrelations. For the most part, no sequences seem to occur more often than random chance would predict. Only a couple of possible serve sequences occur less than random chance would predict. Contrary to the hypothesis, no typical serve patterns that occurred systematically across all players and matches were found.

Regarding the choice of serve direction as a function of previous serves, the results from the tests for serial independence (which were applied to each match, player and court side separately), could be underlined by the conditional probabilities calculated across the complete dataset. Data indicates that players would rather switch from one serve direction to the other, especially when they decided to serve to the right of an opposing player in the preceding serve. Overall, choices of serve directions seem to differ strongly between individual players and matches, resulting in overall high variations in the data and clearly hindering the possibility to detect statistically meaningful effects.

With regard to the serve efficiency, servers generally won a significantly greater amount of points than return players (Gillet, Leroy, Thouvarecq, & Stein, 2009; Magnus & Klaassen, 1999). For the ad-court, servers seem more likely to win the point when they served to the outer sides of the service box as opposed to the central. As the win of the point may not be the best measure to detect efficiency of the serve itself, percentage of serve and return winners were additionally considered. However, analysis revealed no meaningful effects. Generally, servers seem to be more successful when they decide to serve in the opposite serve direction as in the serve before. Thereby, the percentage of points won by the server after an incongruent serve tends to increase with increasing sequence length of identical serve directions. A possible explanation is that return players may expect the continuation of a certain service pattern (e.g., repeated serves to the right) resulting in an additional advantage for the server when he behaves contradictory to this expectation. However, due to high variations in the data and a low number of included cases for the longest sequences, no significant effects where found.

Concerning the serve validity and distribution of first and second serves, findings are in line with previous research studies examining data of professional men's tennis matches (e.g., Loffing et al., 2009). First serves were mostly directed to the outer zones of the service box and second serves were directed mainly to the left (often weaker backhand) side of a return player or to the central, to avoid possible double faults.

6.5 Conclusion

In summary, the elaborate analysis of real match data did not deliver any novel findings. No typical patterns in the servers' choices of serve direction were detected. However, it could be confirmed that tennis players seem to be able to generate sequences of serve directions that correspond to a random sequence. Overall, high variation in the data suggest that serve behavior or choices of serve direction strongly depend on the individual athlete and the match situation.

Regarding the most efficient serve strategy, servers seem to be more successful when they choose to serve in the opposite serve direction of the preceding serve, as opposed to the same direction. Furthermore, the percentage of points won by the server after an incongruent serve tends to increase with increasing sequence length of identical serve direction. This indicates that (1) return players may set subjective probabilities as to the outcome of the next serve based on previous serve directions and (2) that servers may gain an advantage out of this by systematically manipulating these probabilities and subsequently exhibiting an opposite behavior. However, only vague assumptions regarding the decision processes of athletes can be drawn from match data. In Study 2 and 3 I sought to examine the influence of previous event outcomes on anticipation in tennis with the help of two experimental designs.

7 STUDY 2

The examination of real match data can provide an initial understanding of the role and possible effects of patterns in event sequences (here: serves in tennis). However, it does not allow for conclusions to be drawn regarding the direct influence of previous events and patterns in event sequences on anticipatory decisions. Although a player's choices of serve directions has been shown to reflect characteristics of a random generated process (Study 1), this does not mean that the return player perceives this certainty as such, in any circumstance. Rather, a return player may actively search for and rely on patterns in the server's behavior when they make a prediction as to the outcome of the next serve, irrespective of whether a pattern is actually present or not. Study 2 addressed this issue and examined the direct effect of patterns in serve sequences on expectations towards a subsequent serve.

7.1 Study purpose and hypotheses

In Study 2, I sought to examine the effect of patterns in previous serve-sequences of different lengths on anticipation in subsequent serves. For this purpose, both skilled tennis players and novices were asked to anticipate serve direction in a video-based task. Similar to recent research (Farrow & Reid, 2012), serves were presented in blocks of six. Each block contained one target trial where identical serves were presented to control kinematics (for a similar experimental design see Loffing et al., 2015). To test the study aim, target trials were either presented as third or fifth serve in a block and patterns in previous serve outcomes were manipulated under four conditions (all serves to the right: RR / RRRR, all to the left: LL / LLLL, and two alternating patterns: RL / RLRL and LR / LRLR). Prediction accuracy as well as response time was measured. The method will be described in detail in the next section.

Based on previous research findings (e.g., Gray, 2002; Loffing et al., 2015) I suspected that participants would show better anticipatory performance, i.e. higher prediction accuracy and faster response times, in target trials that are congruent (e.g., a serve to the right following four serves to the right) as opposed to incongruent (e.g., a serve to the left following four serves to the right) with the previous pattern. Furthermore, I postulated that this congruence effect would be stronger for sequences of four preceding serves compared to two preceding serves. Analogous to findings from related research in which an effect of sequence length was identified (Huettel et al., 2002), I expected that two subsequent serves would produce a pattern that an observer may be rather uncertain of (e.g., R-L), while four subsequent serves would produce a clearer image of a certain pattern (e.g., R-L-R-L).

In addition, both skilled tennis players and novices were included in the testing to determine whether the size of the congruence effect varied as a function of skill, which has shown to present contradictory findings within the current literature. On one hand, skilled athletes seem more susceptible to contextual cues when compared to less skilled or novice athletes (e.g., Farrow & Reid, 2012; Loffing & Hagemann, 2014a). On the other hand, patterns in previous event outcomes may be a very obvious cue that is (consciously or unconsciously) considered by both skilled and unacquainted observers. Following the findings of Loffing et al. (2015), I expected that a congruence effect would emerge for both skill groups. However, as their findings rest upon varying task difficulties, a clear-cut a priori prediction as to which skill group would be more induced by patterns of previous outcomes was difficult to make.

To further explore the potential sources underlying individual variation in the reliance on previous serve outcome sequences, participants were asked to fill out the Preference for Intuition and Deliberation Inventory (PID; Betsch, 2004) and the Decision-specific Reinvestment Scale (DSRS; Kinrade, Jackson, Ashford, & Bishop, 2010) in a post-experiment questionnaire. Individual characteristics of an athlete may influence anticipatory behavior as evidence regarding the role of individual action capabilities (Dicks et al., 2010) and emotional state (Cocks et al., 2015) has shown. Therefore, it can be understood that preexisting characteristics regarding an athlete's day-to-day decision making capabilities may also be reflected in how anticipatory decisions in sport situations are made. I suspected that particularly participants that are categorized as 'deliberate' according to the PID may be prone to the influence of prior (contextual) information such as patterns in event sequences, while more 'intuitive' participants may be unaffected. Correspondingly, high 'reinvesters' that show a "predisposition for exerting conscious control over their decision-making processes" (Kinrade, 2010, p. 80) may be more greatly influenced by prior information, such as patterns in previous event outcomes, as opposed to participants who score low on the DSRS.

7.2 Method

The experiment was approved by the local ethics committee at the Department of Social Science of the University of Kassel (E05201504).

7.2.1 Participants

Thirty tennis players (age: *M* = 26.13 years, *SD* = 5.24; 15 females) and thirty novices (age: *M* = 32.97 years, *SD* = 2.85; 15 females) voluntarily took part in the experiment. All participants were right-handed and reported normal or corrected-to-normal vision. At the time of testing, tennis players reported to practice *M* = 3.11 hours (*SD* = 1.6) per week and to spend *M* = 3.23 hours (*SD* = 3.96) per week on match-play[12]. On average, they took part in *M* = 10.08 (*SD* = 3.76) tournaments or team competitions a year. Tennis players had *M* = 18.2 years (*SD* = 5.23) overall playing experience and had played in the third to sixth highest division in Germany. Six players reported that they have taken part in international tournaments. The mean Leistungsklasse (official ranking of the German tennis association [DTB]; ranking from 1 (best) – 23 (worst) based on match results in official competitions in the previous season) was 9.37 (*SD* = 3.23). Novice participants had no experience in competitive tennis, however, 15 of them reported that they have played tennis a few times, e.g., during university education, leisure time or schooling.

All participants were naïve as to the purpose of the study and written informed consent approval was obtained prior to testing.

7.2.2 Apparatus and stimuli

Regarding the video material, serves of two right-handed tennis players were recorded using a digital camera (SONY HDR-FX1000). Players performed serves at two different on-court positions near the middle marker of the baseline, according to the deuce and advantage court in a real tennis match. Serves were filmed from the view of a returning

[12] Please note that the testing was conducted during the winter season, in which most of the players reported to only practice half as much as during the summer time.

player awaiting a serve close to the baseline. Therefore, the camera was positioned on a 1.5 m high tripod located in the right (for serves from the deuce court) or left (for serves from the advantage court) corner of the single court (see Fig. 22).

A B

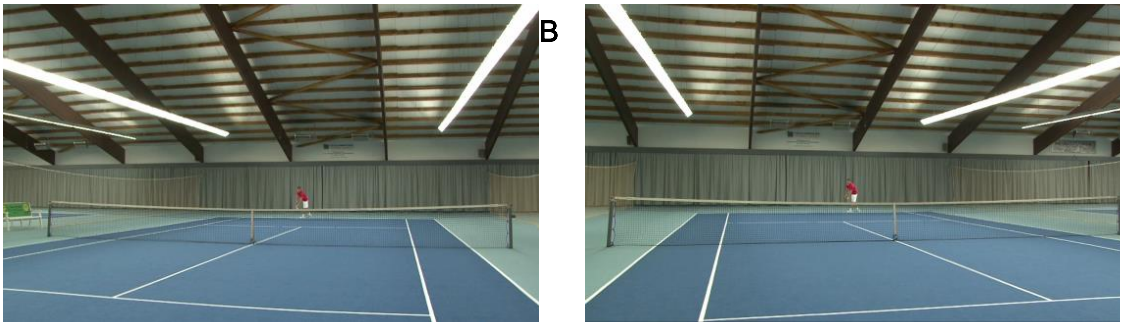


Fig. 22 Detail screen from the raw video material showing a serve from the (A) deuce and (B) advantage court.

The two video models were 27 and 33 years old; both were experienced tennis players (LK 7 and LK 11) and held an official coach license of the German tennis association (DTB). Prior to recording they provided written informed consent as to their participation.

In each clip, a serve was preceded by a short preparation phase, generally a bouncing of the ball. On both deuce and advantage court, service boxes were divided into three sectors of identical width and players were asked to direct serves to each of these sectors. Following video recordings, 12 serves to the inside and 12 serves to the outside per court position (deuce and advantage court) from one of the two players were chosen for further editing, thus resulting in 48 different serves. Additionally, two serves from the deuce court, one per direction, were chosen as target trials. From the other player, only one serve per court position and serve direction was chosen, resulting in four different video clips which later served as practice trials. The selected stimuli were further edited using the video software Adobe Premiere Pro CS4. The size of each video was 1280 x 720 pixels (width x height) and the duration ranged from a minimum of 3200 ms to a maximum of 3400 ms. The experiment was programmed with the software Experiment Builder provided by SR Research.

In the experiment, serves were presented in 64 blocks with six different serves per block. In each block, serves from the deuce and advantage court were presented alternately, corresponding to the common order in real tennis games.

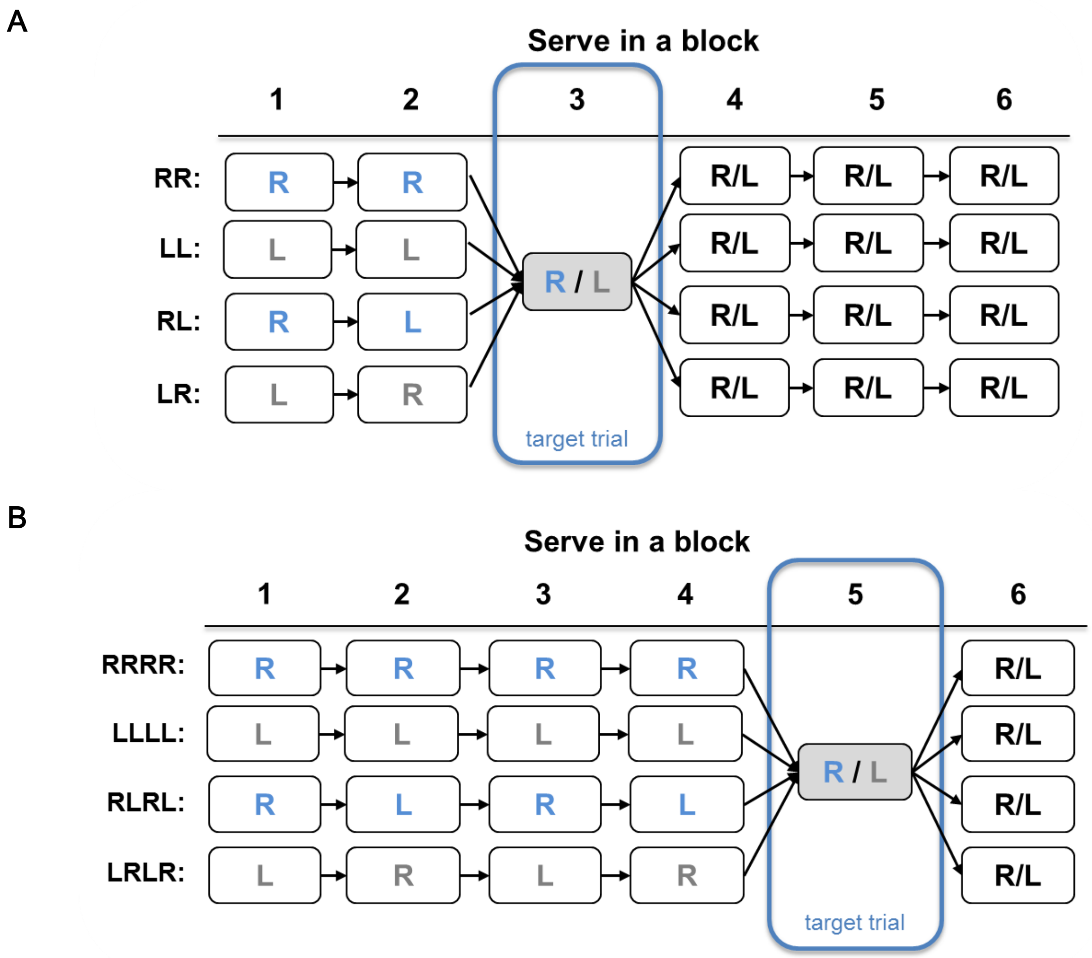


Fig. 23 Order of serve directions in a block / service game. All games contained six serves. In 32 blocks the 3rd serve was the target trial (**A**) and the pattern of serve directions in the previous two serves was manipulated (R-R, L-L, R-L or L-R) while in the other 32 block the 5th serve was the target trial (**B**) and patterns of serve directions in serves 1-4 were varied (all serves to the right or left, R-L-R-L or L-R-L-R). Target trials were either congruent (same colored letters) or incongruent with the previous pattern.

To address the study aim, I selected one serve to the inside (left of the returning player) and one serve to the outside (right of the returning player) from the deuce court as target trials. Each block contained one of the target trials, in which identical serves were presented to control for kinematic information. Thereby, I attempted to isolate the potential effect of biased expectations due to previous serve outcomes and their sequence on prediction performance in the target trials. In half of the games, the third trial served as target trial and the outcomes in trials 1 to 2 were manipulated by presenting either two serves to the right of the returning player (R–R), two serves to the left (L–L), R–L or L–R. Correspondingly, in the other half of the games the fifth trial served as target trial and the outcomes in trials 1 to 4 were manipulated by presenting serves which were directed either entirely towards the right (R–R–R–R), to the left (L–L–L–L) or with alternating outcomes (R–L–R–L, L–R–L–R). Target trials were embedded into a series of trials and therefore were followed by either three (for target trials as third serve) or one (for target trials as fifth serve) successive serve(s), which varied randomly in their outcomes. An illustration of the order of serves in a service game is shown in figure 23. Furthermore, in half of the 32 blocks with a target trial in fifth place, a target trial was additionally shown as first serve (baseline target trial). Through examination of anticipatory performance in target trials presented as first serve, without any previous serves that may lead to a pattern-induced expectation bias, I expected to obtain base rates for prediction accuracy and response time for the target trials.

During the experiment, each of the two target trials was shown 16 times as third serve (each four times preceded by two serves to the right, two serves to the left, R–L and L–R), 16 times as fifth serve (each four times preceded by four serves to the right, four serves to the left, R–L–R–L and L–R–L–R) and eight times as first serve. Target trials were not presented in trials 2, 4 or 6. For the non-target trials in each block, the remaining 48 videos were shown (each at most eight times during the entirety of the experiment and never twice in the same block). Overall, half of the trials included in the experiment demonstrated a serve directed to the right of the returning player and to the left of the returning player, respectively.

7.2.3 Procedure

Participants took part in the study on an individual basis. Prior to the experiment, all participants were provided with a set of standardized, written instructions and part one of a questionnaire which included questions regarding demographic details and experience in tennis, of which they were required to complete.

For the experimental portion of the session, participants were asked to watch videos of tennis serves on a 15’’ notebook monitor from a seated position (eye-to-screen distance approximately 60 cm). Videos were occluded 40ms after racket-ball-contact (in non-target trials) or at racket-ball-contact (in target trials). Choosing a later occlusion point in non-target trials allowed for higher prediction accuracy as the first part of the ball trajectory was visible. This was intended due to the fact that, in real tennis matches, return-players usually initiate their response movement in the correct direction or are able to modify their movement as ball-flight information becomes available, which is reflected in the relatively low percentage of points won through aces in professional tennis (e.g., Cross & Pollard, 2009; Loffing et al., 2009). Additionally, task difficulty has been shown to disproportionately affect the motivational capacity of a novice athlete's performance (Loffing et al., 2015). Therefore, "easier" non-target trials were implemented to keep participants motivated throughout the experiment. In each trial, subjects were asked to predict the serve direction as accurately and quickly as possible by pressing either the 'LCTRL' button (serve directed to the observer's left side) or the 'delete Num-Pad' button (serve directed to the observer's right side) on a German QWERTZ keyboard. The keys were marked so they depicted the letter 'L' or 'R' respectively. Before the start of the experimental trials, participants completed four practice trials to familiarize themselves with the task. These trials showed serves by a second player who was not included in the experimental trials. After reassuring that the participants fully understood the task, the experimental trials commenced. For each participant, the 64 blocks were presented in a different randomized order which was determined by the experimental software. For each trial, the participants were provided with feedback on the effective serve direction after having made a prediction in each trial. Feedback was provided via presenting the off-cut of the video, starting at the occlusion point and ending with the ball leaving the display on the left or right edge. The provision of feedback was necessary to allow for the examination of the effect of previous serve outcomes and their sequence on expectation bias in prediction performance during target trials.

After 16 blocks (i.e., 96 trials) at a time, participants were required to take a break of at least one minute (as prompted by the experimental software) before continuing with the remaining serve blocks.

Following the experiment, participants were asked to fill out part two of the aforementioned questionnaire which included questions regarding the course of the experiment. Amongst others, these contained five questions aimed at identifying whether the participants were aware of the experiment's video manipulation. These included:

- Question 1: Did you have the feeling that, in the experiment, identical videos were presented multiple times? (Yes/No)

- Question 2: If 'yes' did you think there was a specific position in service games (i.e., 1st, 2nd, 3rd, 4th, 5th or 6th serve) where identical videos were presented in particular? (Yes/No)
- Question 3: If 'yes', please check (on a scale from 1-6) the serve number of which you think identical videos were presented in particular.
- Question 4: Did you have the feeling that particular patterns or regularities were present in the sequence of videos within the service games, which allowed identifying serve outcomes? (Yes/No)
- Question 5: If 'yes', please describe these patterns or regularities in the following.

Additionally, individual characteristics pertaining to decision making ability were assessed via the Preference for Intuition and Deliberation Inventory (PID; Betsch, 2004) and the Decision-specific Reinvestment Scale (DSRS; Kinrade et al., 2010).

In total, the entirety of the testing took about 70 min to complete.

7.2.4 Data analysis

The dependent variables analyzed during this study included prediction accuracy and response time. Prediction accuracy was calculated by determining the percentage of correct serve direction predictions, while response time was calculated by determining the time difference (in milliseconds) between the end of a video and the moment of a participant's key press. To calculate response times for each participant under each of the experimental conditions, the median was used to circumvent the distortion of the results by potential outliers.

With respect to the analysis of anticipatory performance in target trials in third or fifth place of a block, data was differentiated according to the three experimental factors. These factors included *Length of the Sequence* (two or four preceding serves), *Congruence* and *Pattern of previous serve outcomes* in trials 1 to 2 and 1 to 4 respectively (i.e. only serves to the right, only serves to the left, and two alternating patterns). *Congruence* refers to whether the serve direction in a target trial was congruent with the pattern in the sequence of the previous serve directions (i.e., a serve to the right following two/four serves to the right or R–L/R–L–R–L, or a serve to the left following two/four serves to the left or L–R/L–R–L–R) or not (incongruent: a serve to the right following two/four serves to the left or L–R / L–R–L–R or a serve to the left following two/four serves to the right or R–L/R–L–R–L). To check for overall effects in the dependent measures, data regarding prediction accuracy and response time was analyzed separately using two 2 (Skill) x 2 (Length) x 2 (Congruence) x 4 (Previous Pattern) mixed ANOVAs with skill as between-subjects factor and repeated measures on the last three factors.

For baseline target trials (shown as first serve), mean prediction accuracy and median response times were calculated across all trials, and tennis players' and novices' performance was compared by the means of t-tests for independent samples. Furthermore, differences in mean prediction accuracy between baseline target trials and target trials presented as third or fifth serve were calculated.

With respect to the analysis of anticipatory performance in non-target trials, prediction accuracy and response time were calculated across all non-target trials. Anticipatory performance of tennis players and novices were compared by means of t-tests for independent samples. Additionally, for target and non-target trials, one sample t-tests were conducted to determine whether or not both groups' performance differed from chance (50% prediction accuracy).

With regard to the analysis of the Preference for Intuition and Deliberation Inventory (PID; Betsch, 2004) a median split of the PID-Intuition and the PID-Deliberation scales was used to differentiate between intuitive, deliberative and situation-specific participants. People above the median of PID-Intuition and below the median of PID-Deliberation were classified as intuitive, while people above the median of PID-Deliberation and below the median of PID-Intuition were classified as deliberate. This procedure is generally recommended to analyze PID (Betsch, 2008, p. 248). Additionally, people that scored either high or low on both scales were classified as situation specific (Laborde, Dosseville, & Kinrade, 2014). With the help of a one-way ANOVA values of absolute differences in prediction accuracy between baseline target trials and target trials presented as third or fifth serve, as an indicator for susceptibility to patterns in previous event outcomes, were compared between the three groups. Concerning the Decision-specific Reinvestment Scale (DSRS; Kinrade et al., 2010), mean values were calculated for each participant, separately for DSRS-Reinvestment and DSRS-Rumination. Subsequently, a Pearson product-moment correlation coefficient was computed to assess the relationship between the values of DSRS-Reinvestment and DSRS-Rumination, respectively, and the absolute differences in prediction accuracy between baseline target trials and target trials presented as third or fifth serve, as an indicator for susceptibility to patterns in previous event outcomes.

All analyses were conducted using IBM SPSS Statistics 23. Alpha was set at .05 and partial eta-squared values were calculated as effect size measure for ANOVA. Exploratory Software for Confidence Intervals (ESCI) was used for the calculation of Cohen's d_{unb} (an unbiased estimate of the population effect size δ) and 95 % confidence intervals (see Cumming, 2012, for details).

7.3 Results

7.3.1 Manipulation check

To identify whether or not the participants were aware of the video manipulation, they were asked specific questions (see 5.2.3) in a post-experimental questionnaire. Out of a total of 60 participants, 29 novices and 26 tennis players felt that identical videos were presented multiple times. However, only 8 of the novices and 12 of the experts thought there was a specific position in the service games in which identical videos were presented. When asked to name the position, only one participant (novice) named all possible target trial positions, reflecting no. 1, 3, and 5. Five participants named no. 3 and two named no. 5, while the others named no. 2, 4 or 6. Furthermore, when asked whether the sequences of videos within service games followed a particular pattern or regularity, 19 participants selected 'yes'. Three of these participants reported that they felt in several service games serves were repeatedly directed to the same location and one named the detection of an alternating service pattern. While part of serve sequences was identified by some participants, none of them reported to have detected the full set of serve sequence manipulations. Therefore, all data was included in the analysis.

7.3.2 Target trials

7.3.2.1 Prediction accuracy

The ANOVA revealed that a main effect was present for the *Congruence* factor, $F(1, 58) = 43.01$, $p < .001$, $\eta_p^2 = .43$, as well as a significant *Length x Congruence* interaction, $F(1, 58) = 5.62$, $p = .021$, $\eta_p^2 = .09$. Accuracy was higher in congruent ($M = 67.3\%$, $SD = 12.0\%$) compared to incongruent ($M = 55.2\%$, $SD = 10.4\%$) trials, $t(59) = 6.534$, $p < .001$, $d_{unb} = 1.06$, 95% CI [0.70, 1.45].

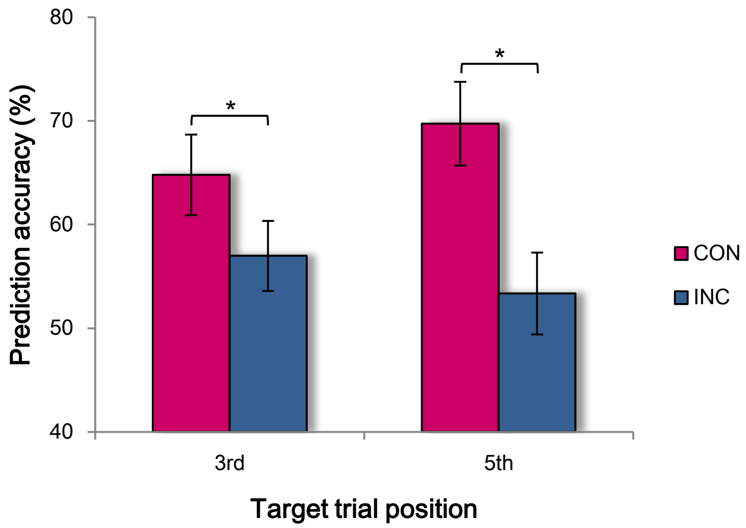


Fig. 24 Prediction accuracy (%) in congruent and incongruent target trials as a function of length of the sequence of previous serves. Target trials were either presented as 3rd serve or 5th serve. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Through visual inspection of Fig. 24, and further exploration of the two-way interaction through pairwise comparisons, it is suggested that this congruence effect was stronger for longer sequences (target trials preceded by four serves), $t(59) = 5.75$, $p < .001$, $d_{unb} = 1.05$, 95% CI [0.65, 1.47], when compared to shorter sequences (target trials preceded by two serves), $t(59) = 3.37$, $p = .001$, $d_{unb} = 0.55$, 95% CI [0.22, 0.89]. Furthermore, for shorter sequences, participants performed above chance in congruent, $t(59) = 7.64$, $p < .001$, $d_{unb} = 0.98$, 95% CI [0.68, 1.30], and incongruent trials, $t(59) = 4.14$, $p < .001$, $d_{unb} = 0.52$, 95% CI [0.26, 0.80], whereas for longer sequences, participants performed above chance in congruent, $t(59) = 9.77$, $p < .001$, $d_{unb} = 1.24$, 95% CI [0.93, 1.60], but not in incongruent trials, $t(59) = 1.69$, $p = .096$, $d_{unb} = 0.22$, 95% CI [-0.04, 0.48].

None of the remaining main or interaction effects were statistically significant.

7.3.2.2 Response time

The ANOVA did not reveal a main effect for the *Skill* factor or any of the other three factors. Mean response time in target trials was 540.68 ms (*SD* = 214.85 ms) for tennis players and 547.37 ms (*SD* = 180.85 ms) for novices. Only a significant *Congruence x Pattern of Previous Serve Outcomes* interaction was found, *F*(2.828, 164.048) = 3.701, *p* = .015, η_p^2 = .06. Visual inspection of Fig. 25 demonstrates that differences in response times between congruent and incongruent trials varied across patterns. Particularly, when dependent on the pattern, response times were higher or lower for congruent as opposed to incongruent trials. Further exploration through pairwise comparisons suggests that for the pattern R-L / R-L-R-L of previous serve outcomes (irrespective of the sequences' lengths) response times were higher in incongruent (*M* = 602.91 ms, *SD* = 212.72 ms) when compared to congruent (*M* = 546.31 ms, *SD* = 243.45 ms) trials, *t*(59) = 2.13, *p* = .037, d_{unb} = 0.25, 95% CI [0.02, 0.48] . No considerable differences in response times, between congruent and incongruent trials, were found for the other three patterns of previous serve outcomes.

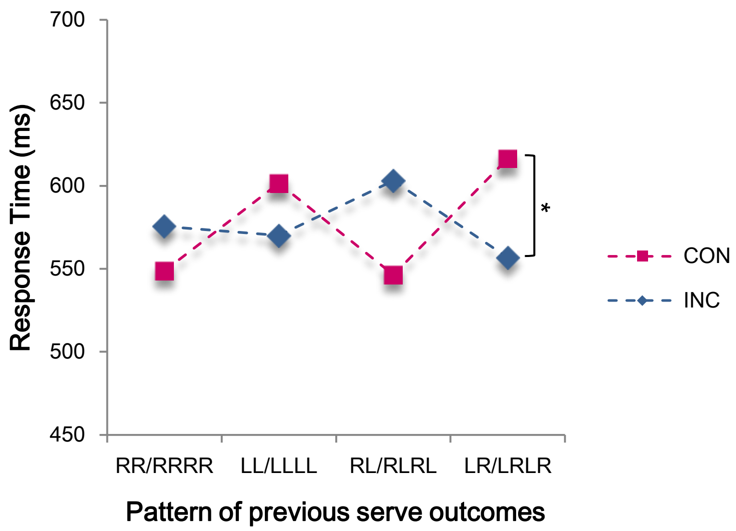


Fig. 25 Response times (ms) in target trials that were either congruent or incongruent with a certain pattern of previous serve outcomes. Error bars represent 95%-confidence intervals, * ≙ p < .05.

7.3.3 Baseline target trials

7.3.3.1 Prediction accuracy

For target trials presented as first serve, no differences in prediction accuracy between tennis players (M = 64.17%, SD = 13.02%) and novices (M = 61.46%, SD = 16.83%) were found, $t(58)$ = .697, p = .488, d_{unb} = 0.18, 95% CI [-0.33, 0.69]. Tennis players, $t(29)$ = 5.96, p < .001, d_{unb} = 1.06, 95% CI [0.63, 1.54], and novices, $t(29)$ = 3.73, p = .001, d_{unb} = 0.66, 95% CI [0.28, 1.07], performed above chance.

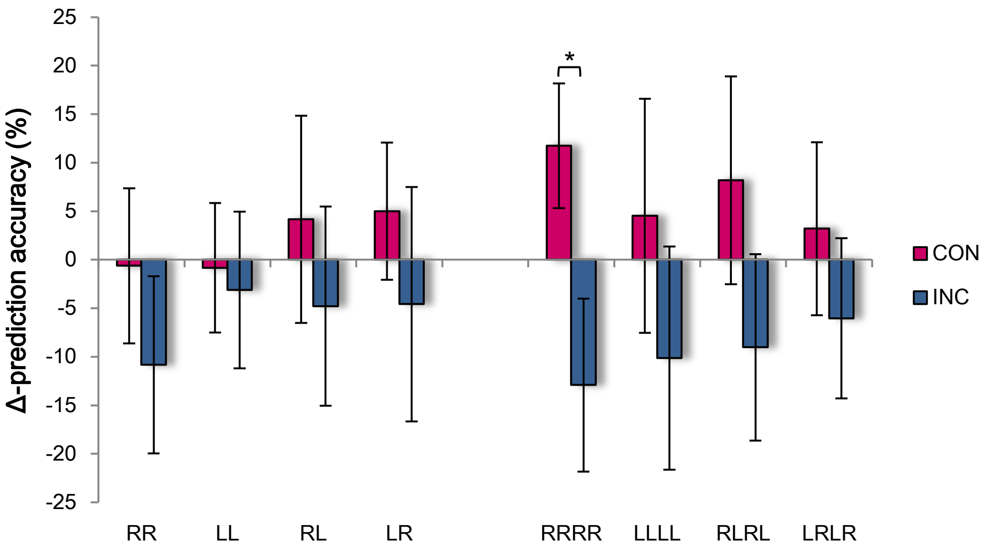


Fig. 26 Δ-prediction accuracy in congruent and incongruent target trials compared to the corresponding baseline target trials (presented as 1st serves with no preceding pattern). Negative values indicate a higher accuracy in baseline target trials compared to target trials at 3rd/5th position, and vice versa. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Figure 26 shows the mean difference between baseline target trials and target trials presented in subsequence to sequences of two or four preceding serves. Visual inspection suggests that prediction accuracy was higher relative to baseline target trials especially for congruent target trials at fifth position. Conversely, accuracy in incongruent target trials at fifth position seemed lower compared to baseline target trials. However, due to high variability in response data, analysis revealed no statistically reliable effects for Δ-prediction accuracy for the majority of patterns. Mean differences in prediction accuracy between baseline target trials and target trials differed significantly from zero for the patterns R-R-R-R in congruent, $t(59)$ = 3.649, p = .001, d_{unb} = 0.47, 95% CI [0.20, 0.74], and incongruent trials, $t(59)$ = -2.901, p = .005, d_{unb} = 0.37, 95% CI [0.11, 0.64], and for the pattern R-R in incongruent trials, $t(59)$ = -2.376, p = .021, d_{unb} =

0.30, 95% CI [0.05, 0.57]. Furthermore, for the pattern R-R-R-R, Δ-prediction accuracy differed decisively between congruent (*M* = 11.74%, *SD* = 24.91%) and incongruent (*M* = -12.92%, *SD* = 34.49%) trials, *t*(59) = 4.55, $p < .001$, d_{unb} = 0.81, 95% CI [0.43, 1.20].

7.3.3.2 Response time

For target trials presented as first serve, no differences in response times between tennis players (*M* = 560.04 ms, *SD* = 283.12 ms) and novices (*M* = 541.75 ms, *SD* = 218.28 ms) were found, *t*(58) = -.28, *p* = .78, d_{unb} = -0.07, 95% CI [-0.58, 0.43].

7.3.4 Non-target trials

7.3.4.1 Prediction accuracy

For prediction accuracy in non-target trials, tennis players (*M* = 91.41%, *SD* = 6.58%) were superior to novices (*M* = 87.42%, *SD* = 7.29%), *t*(58) = 2.23, *p* = .03, d_{unb} = 0.57, 95% CI [0.06, 1.09]. Furthermore, both groups performed clearly above the level of chance: tennis players: *t*(29) = 34.496, $p < .001$, d_{unb} = 6.13, 95% CI [4.64, 7.95]; novices: *t*(29) = 28.117, $p < .001$, d_{unb} = 5.00, 95% CI [3.77, 6.49].

7.3.4.2 Response time

No significant differences in response times between tennis players (*M* = 374.44 ms, *SD* = 124.46 ms) and novices (*M* = 402.44 ms, *SD* = 88.96 ms) were found, *t*(58) = 1.003, *p* = .32, d_{unb} = 0.26, 95% CI [-0.25, 0.77].

7.3.5 Individual differences

7.3.5.1 Preference for Intuition and Deliberation

Following the analysis of participants' scores in the PID-Inventory, 26 participants were classified as intuitive (novices: 12, tennis players: 14), 18 were classified as deliberate (novices: 10, tennis players: 8) and 16 were classified as situation specific (each group: 8). The one-way ANOVA did not reveal alternations between the groups in the absolute differences in prediction accuracy between baseline target trials and target trials presented as third or fifth serve, *F*(2, 57) = 0.264, *p* = .77. Participants classified as intuitive (Δ-prediction accuracy: *M* = 29.79%, *SD* = 6.89%), deliberate (*M* = 28.71%, *SD* =

7.35%) or situation specific (*M* = 30.44%, *SD* = 7.09%) did not differ in their susceptibility to patterns in previous event outcomes.

7.3.5.2 Decision-specific Reinvestment

With regard to the DSRS, separate values for the DSRS-Reinvestments and DSRS–Rumination were calculated for each participant by taking the mean of the corresponding items. No correlation was found between DSRS-Reinvestment and Δ-prediction accuracy between baseline target trials and target trials, $r = -.102$, n = 60, $p = .44$, or between DSRS-Rumination and Δ-prediction accuracy, $r = .093$, n = 60, $p = .48$. The results are illustrated in Fig. 27.

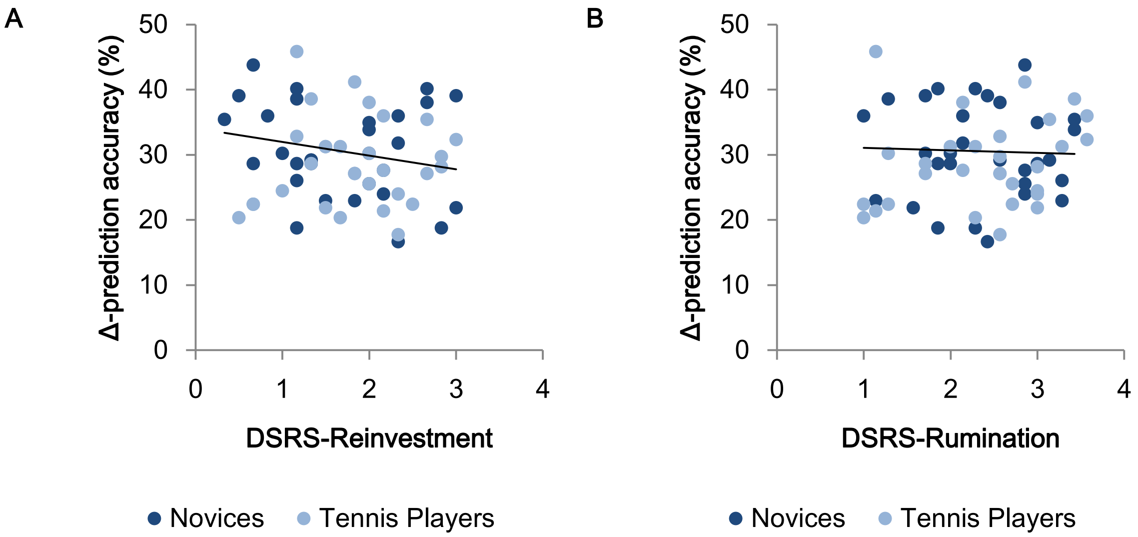


Fig. 27 Scatterplots showing the relationship between the values of DSRS-Reinvestment and DSRS-Rumination, respectively, and the absolute differences in prediction accuracy between baseline target trials and target trials presented as 3rd or 5th serve.

7.4 Discussion

Skilled visual anticipation seems to be driven by cues derived from an opponent's kinematics and/or non-kinematic cues, such as on-court position (Loffing & Hagemann, 2014a) or previous action events (Gray, 2002; Loffing et al., 2015). Here, it was examined whether patterns of previous tennis serve outcomes influence anticipatory behavior in subsequent serves. Specifically, the main intent was to determine (1) whether visual anticipation of tennis serves differ in trials which are congruent vs. incongruent with the pattern of preceding serve outcomes and (2) whether the length of the preceding sequence moderates the role of the previous pattern.

7.4.1 Performance in congruent vs. incongruent target trials

With regard to the main intention of this study, it is pertinent to note that (1) a congruence effect for the dependent variable prediction accuracy was found, and (2) that this effect was moderated by the length of the preceding sequence. Similar to previous findings (e.g., Gray, 2002; Loffing et al., 2015) participants showed higher prediction accuracy in trials that were congruent with the pattern of previous serves indicating that they expected the continuation, rather than a discontinuation, of a serve pattern in target trials. This phenomenon has been suggested to be caused by the natural process of human cognition, where one has the potential to extract regularities from temporal sequences of events and to form predictions about upcoming events on the basis of the identified patterns (Huettel et al., 2002; Oskarsson et al., 2009). Additionally, the congruence effect occurred irrespective of the type of previous pattern (for similar findings see Loffing et al., 2015). Furthermore, a significant interaction was found between the *Length of the sequence* and *Congruence* factors. As hypothesized, the congruence effect was stronger for target trials that were preceded by four serves, as compared to two. It can be suggested, that two subsequent serves produce a pattern that an observer may be rather uncertain of (e.g., R-L), while four subsequent serves produce a clearer image of a certain pattern (e.g., R-L-R-L). Correspondingly, studies on dynamic processing of sequences of events in the prefrontal cortex showed that prefrontal activation is evoked by violations of both repeating and alternating patterns in series of events and that the amplitude of this activation increases with increasing pattern length (Huettel et al., 2002). Huettel et al. (2002) suggest that while only a few repetitions are needed before a predictive model is established for repeating patterns, alternating or even more complex patterns require a greater number of occurrences before a predictive model is established. Accordingly, it could have been suspected that a congruence effect will be stronger for repeating patterns (e.g., RR/RRRR and LL/LLLL) as opposed to alternating patterns (e.g., RL/RLRL and LR/LRLR). However, no correspondent evidence was found in the data.

Visual inspection of the differences in prediction accuracy in target trials compared to baseline target trials (Fig. 26) suggests that the congruence effect is not only due to lower performance in incongruent trials (cf. Loffing et al., 2015) but also to higher performance in congruent trials. This suggests that relying on patterns of previous outcomes is beneficial when the pattern actually continues, as was the case in congruent trials. On the other hand, it can be detrimental if a pattern is broken, as was the case in incongruent trials (Gray, 2002; for similar detrimental effects see Loffing et al., 2015; D. L. Mann et al., 2014).

Contrary to the hypothesized results, no congruence effect was found for the response time variable. It was assumed that a pattern-induced expectation bias may not only lead to variations in predictions accuracy in target trials but also to assimilations in response times. Specifically, shorter response times were expected for congruent trials and longer response times for trials that were incongruent with a preceding pattern. However, no such relationship could be detected. Interestingly, an interaction was found between the *Congruence* factor and *Pattern of previous serves* factor. For the pattern R-L/R-L-R-L response times were significantly faster for congruent trials when compared to incongruent ones. However, no considerable differences in response times between congruent and incongruent trials were found for the other three patterns of previous serve outcomes. Broader visual inspection of Fig. 23 suggests that across all patterns response times were longer for target trials that contained serves to the left side of the observer (i.e. congruent trials for the patterns L-L/L-L-L-L and L-R/L-R-L-R and incongruent trials for the patterns R-R/R-R-R-R and R-L/R-L-R-L) compared to serves to the right side. To determine whether overall differences in mean response times between serves to the right and to the left of an observer were existent in the experiment, mean response times for serves to the right and to the left across all trials were compared by means of a t-test for dependent samples. Accordingly, response times differed significantly for serves to the right and to the left. However, contrary to expectation, response times were faster for serves to the left (M = 389.16 ms, SD = 109.86 ms) compared to responses for serves to the right (M = 434.18 ms, SD = 142.64 ms), $t(59) = 6.053$, $p < .001$, $d_{unb} = 0.77$, 95% CI [0.49, 1.07].

As a potential limitation with regard to response time measurement, it must be noted that reactions (or predictions) were only accepted after the end of a video. That is, a button press that occurred prior to the end of a clip was not registered by the experimental software, but only button presses that were made after the end of a clip. This was done to ensure that participants watched videos in full length before making a decision. I cannot exclude the possibility that this procedure may have introduced a bias in RT measurement.

Both skilled tennis players and novice were included in the testing to check whether the size of the congruence effect varied as a function of skill. However, regarding the performance in congruent and incongruent target trials, no skill effect was found. Accordingly, the outcome of previous events and moreover, patterns in previous events, may be a salient cue for both experts and novices, when predicting future events. This encourages previous findings of Loffing et al. (2015) on a pattern-induced expectation bias when anticipating opponent's actions in volleyball. However, it must be noted that their findings rest upon varying task difficulties while in this experiment, both groups faced the same task difficulty. As previous action outcomes can be classified as action-independent cues (see chapter 2.4.3), results are in line with other research studies indicating that such cues may influence anticipatory performance of both, skilled and less-skilled athletes (Barton et al., 2013; Loffing et al., 2015; Paull & Glencross, 1997). On the contrary, action-dependent contextual cues (e.g., players' on-court position) seem to be a salient cue especially for experienced players (Abernethy et al., 2001; Loffing & Hagemann, 2014a), as the knowledge of task-specific constraints or the like is necessary to identify varying probabilities associated with action-dependent cues. It can be suggested that novice players lack this knowledge, potentially resulting in a uselessness of such information for them.

7.4.2 Performance in baseline target trials and non-target trials

Regarding the prediction accuracies in baseline target trials, tennis players reached higher prediction accuracies than their novice counterparts; however, statistical analysis did not provide support for a skill effect in these trials. This finding is contradictory to other research studies using a progressive temporal occlusion paradigm and showing for racket sports and tennis in particular, that experts outperform novices especially at early occlusion points (for an overview, see Cauraugh & Janelle, 2002). However, a rather late occlusion point (racket-ball-contact) was chosen in this study, leading to the possibility of attenuating a potential skill-effect. For baseline target trials, no differences in response times were found for tennis players and novices.

The skill difference found in prediction accuracy for non-target trials indicates that the experiment allowed capturing components of tennis-specific perceptual cognitive expertise. However, the task in non-target trials in which videos were not occluded until one frame after the racket ball contact, enabled both tennis players and novices to reach very high prediction accuracies and therefore limited the possibility to detect expert-novice differences. For non-target trials, both groups performed well above chance level. This was not surprising, as a relatively late occlusion point, which allowed visual availability of the first 40ms of ball flight, was chosen due to the aforementioned reasons. Nevertheless, a small difference was found and as response times did not vary between tennis players and novices, it can be assumed that the higher prediction accuracy of tennis players was not at the expense of later responses.

7.4.3 Role of individual differences

Individual factors such as an athlete's physical capabilities (e.g., movement speed, Dicks et al., 2010) and emotional state (e.g., anxiety, Cocks et al., 2015) are assumed to influence the anticipation process in time-constrained sport situations (see chapter 2.4.3.1). Beyond domain-specific skills, it was suggested that anticipatory decisions may underlie further characteristics of an individual. Results of the Preference for Intuition and Deliberation Inventory (PID; Betsch, 2004) and the Decision-specific Reinvestment Scale (DSRS; Kinrade et al., 2010) were not connected in any way with Δ-prediction accuracy, indicating that individual characteristics reflecting how decisions are made does not seem to influence susceptibility to patterns in event sequences. There are two possible explanations for the absence of an effect: First, individual characteristics regarding general decision making do not reflect how anticipatory decisions in sport situations (here: tennis) are made. Second, the two inventories are not adequate to reveal the specific individual factors determining anticipatory decision making in sports. In studies on anticipation in sports, the inclusion of supplemental measurements of individual characteristics adjacent to domain-specific skill is to date rather uncommon. Future studies taking this aspect into account may shed more light on the role of individual differences for anticipatory decision making.

7.4.4 Study limitations and research perspectives

While the findings contained herein certainly provide a contribution to the examination of the role of contextual cues (here: outcomes of previous events) for visual anticipation, it is important to acknowledge the apparent limitations which exist.

The first limitation reflects the decision of choosing the third or fifth serve in each block as the intended target trials, in which the server's kinematics were kept constant. Hence, the factor length was additionally considered and previously reported limitations in similar studies (Gray, 2002; e.g., Loffing et al., 2015) were partially negotiated. However, as event history seems to influence expectations in interceptive tasks, even if only one preceding trial is considered (de Lussanet et al., 2001, 2002), other possible sequence lengths should be included in future analysis.

Another limitation evident in this study reflects the use of only four different patterns of serve directions when further possible patterns (for sequences of four successive serves) exist and of which, have been shown to occur even more frequently in real tennis games (see Study 1). Here, however, length of the sequence was chosen as a factor and I therefore decided to implement patterns that would permit the comparison of two different lengths by producing a similar pattern in two and four previous serves (e.g., R-L and R-L-R-L).

A third potential limitation to this study, as referenced by some of the current literature in the field, reflects the notion that each point in a tennis match is considered to be a simple 2 x 2 constant-sum normal-form game (e.g., Walker & Wooders, 2001) and therefore, points played from the deuce and advantage court are considered separately as they represent two diverging situations. Following this perspective, one could argue that sequences of serves from the deuce court and from the advantage court and their particular influence on expectations on a subsequent serve from the corresponding side should have been considered separately. However, in this study, sequences of serves from the deuce and advantage court were not considered to operate discretely but rather, examined from both sides in an alternating manner. This limitation suggests that a potentially stronger congruence effect may have been present for patterns in sequences of serves from the same court.

Utilization of the particular testing environment brings to light the fourth potential limitation herein, as the perception of the participants was decoupled from their corresponding action. In the study, participants were asked to watch videos on a customary computer screen and press a button to make their anticipatory decision. Against the background of perception-action coupling (Goodale & Milner, 1992; Van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008), this test design clearly limits the transferability of the findings to real world tasks. Therefore, testing participants in front of large-scale video projections or in real sport situations should be a future step for investigating effects of event history or other contextual cues on visual anticipation.

A fifth limitation which should be noted is reflected in the observation of the response time results. In particular, it must be noted that the time for the response was not limited and that the experimental software did not allow for responses earlier than the occlusion point (which corresponds to the racket-ball-contact in target trials). This restriction could have possibly caused a distortion of the results and masked a possible skill effect in response times which was repeatedly found in earlier anticipation studies (see the meta-analysis by D. T. Y. Mann et al., 2007). In order for future researchers in the field to gain a better understanding of response times, the aforementioned limitations should be mitigated. Furthermore, the exploration of convenient possibilities for measuring response times in more natural test environments (e.g., via contact-mats or photo sensors) should be considered as an avenue to augment the potential for further discovery.

A final limitation present in this study is reflected in the experimental method of service, where serves were presented irrespective of the subsequent rally, which does not accurately reflect the portrayal of real tennis matches, where serves followed by only one adjacent shot of the returning player is not the rule. Therefore, it can be assumed that when a sequence of serves is repeatedly broken by rallies that occasionally consist of a large number of subsequent shots, the pattern of such a sequence may not be as salient for an observer. However, a serve in tennis is an event that clearly differs from subsequent shots and therefore it is expected that the congruence effect found herein may at most be slightly reduced when confronting participants with ongoing rallies between the presented serves.

7.5 Conclusion

In Study 2 I sought to examine whether the outcome of previous serves in tennis influenced the expectations and thereby the anticipatory behavior in subsequent serves within a service game. In particular, testing was designed to determine whether participants expected a continuation or disruption of a certain pattern in servers' choices of serve direction. Indeed, results showed a pattern-induced expectation bias. Participants reached higher prediction accuracies in serves that were congruent with a previous pattern of repeated serves to the same direction or alternating serve directions, respectively, when compared to incongruent serves. This indicates that they expected a pattern to continue rather than to be disrupted. The effect was additionally moderated through the length of a presented pattern. The congruence effect was stronger when a serve was preceded by four serves as opposed to two, which implicated a certain pattern in the server's choices of serve direction. From this information we can derive two practical implications. On the one hand, servers may take advantage of a return player's susceptibility to patterns in their choice of subsequent serve directions. This suggests that servers may try to manipulate their opponent's subjective probabilities as to the outcome of the next serve by initially producing a specific sequence of serve directions, e.g., right – left – right – left, and to then break the sequence by serving to the left (i.e., performing an incongruent action). On the other hand, athletes should be made aware and receptive of the possible adverse effects of forming expectations based on serve directions of prior serve outcomes such that they may be more attentive to anticipation-relevant kinematic cues.

Overall, findings are in accordance with the assumption that athletes rely on both kinematic and contextual cues when visually anticipating opponent's action intentions (Buckolz et al., 1988; Loffing & Hagemann, 2014a; Loffing et al., 2015). Outcomes of previous events and moreover, patterns in the outcomes of previous events, affect visual anticipation even in the concurrent presence of opponent's kinematics (Gray, 2002; Loffing et al., 2015). Additionally, the length of a presented pattern influences the strength of this effect. Furthermore, findings suggest that pattern-induced expectations may not be specific to skilled athletes. If anything, previous event outcomes may be a salient contextual cue for both skilled athletes and novices. Besides the conducted subdivision into (inter)action-independent and (inter)action-dependent contextual cues (see chapter 2.4.3), these findings suggest that an alternative classification of skill-independent and skill-dependent contextual cues may be valuable. While research indicates that e.g., a player's on-court position (Loffing & Hagemann, 2014a) seems to be a salient cue especially for experienced players, and hence a skill-dependent contextual cue, patterns in previous event sequences may influence anticipatory behavior irrespective of skill. However, the majority of existing research examining the role of contextual cues does not implement an expert-novice study design that allows for the detection of a possible skill-(in)dependence based on certain contextual cues. Consequently, more research is needed to address this issue.

8 STUDY 3

Event sequences (and patterns in the event outcomes) occur not only in a server's choices of serve direction but also in a player's choices of shot directions during rallies. Consistent with previous research findings demonstrating a pattern-induced expectation bias when anticipating opponent's actions in volleyball (Loffing et al., 2015) and earlier research studies indicating a non-negligible effect of previous event outcomes on expectations towards a future event (e.g., Gray, 2002), Study 2 revealed a pattern-induced expectation bias when anticipating opponent's serves in tennis. Correspondingly, it can be assumed that the outcome of previous shots, and moreover, patterns in a player's choices of shot directions during rallies, influences anticipation of subsequent shots. In Study 3 I sought to address this issue in order to shed more light on the effect of event sequences when anticipating opponent's actions in tennis.

8.1 Study purpose and hypotheses

Study 3 examined whether previous actions of an opponent, particularly patterns in these actions, influence anticipation of action outcomes in tennis. While Study 2 focused on the examination of the effect of patterns in serve sequences, Study 3 looks at whether patterns in an opponent's shot directions within rallies affect anticipatory performance and, in a second step, how different sequence lengths may moderate such an effect. To this end, skilled tennis players and novices were asked to anticipate shot directions in tennis rallies in a video-based task. Each rally contained one target trial where identical shots were presented in order to control for the player's kinematics. To test the first study aim, target trials were presented as the fourth shot in a rally and patterns in previous shot outcomes were manipulated under three conditions:

- all strokes cross-court to the right side of the receiver (CCC),
- all down-the-line to the left side (LLL) or
- alternating patterns (CLC / LCL).

Prediction accuracy as well as response time was measured. To test the second study aim, target trials were also presented as third, second or first shot in a rally. For patterns with identical outcomes (i.e. CCC and LLL) the length of the sequence of previous shots was examined in order to determine whether or not there was an influence on anticipatory behavior in a subsequent shot. The method will be described in detail in the next section.

8.1.1 Research question 1

For target trials presented as fourth shot in a rally, the influence of three different patterns in an opponent's choices of shot directions was investigated (CCC, LLL, and CLC / LCL). Based on the results of Study 2, as well as recent evidence (e.g., Gray, 2002; Loffing et al., 2015), it was suspected that participants would show varying anticipatory performance in target trials depending on which pattern of shot directions was presented. While in Study 2 it was assumed that participants would show higher prediction accuracy and faster response times in target trials that are congruent with a previous pattern (e.g., a cross-court shot to the right of a receiver following three cross-court shots [CCC] or the pattern down-the-line/cross-court/down-the-line [LCL]) as opposed to incongruent (e.g., a down-the-line shot to the left of a receiver following CCC or LCL), here, the formulation of such a definite hypothesis was more difficult. First, it must be noted that the serve, which was the object of investigation in Study 2, clearly depicts a different situation than a rally. In tennis rallies, the choice of shot directions is determined mostly by the tactical play of a player as she or he tries to make it as hard as possible for their opponent to reach and successfully return the ball. However, as the opposing player basically has the same goal, the sequence of shot directions evolves from interplay between the two players. While laymen would likely postulate that it is most beneficial to simply alternate shot directions to force an opponent to run from one side to the other (which is in fact beneficial), a further tactic known amongst tennis players is to anticipate that an opponent will expect such a behavior and purposely aim the ball against the run direction of an opponent, which means in the same direction as the previous shot (e.g., Kuehn, 2017). The success of this tactic, referred to as "wrong-footing" the opponent (Nguyen), however, strongly depends on the moment of time in which it is used during the rally, as the element of surprise is crucial. Amongst other things, this tactical specialty complicates the formulation of a clear-cut a priori prediction as to how these different patterns influence expectations towards a subsequent shot. However, as rallies with alternating shot directions occur more frequently than others, it was assumed that participants would rather expect a change of direction as opposed to yet another shot in the same direction. For repeating patterns (CCC and LLL), it was expected that prediction accuracy will be higher and decision time will be lower in incongruent (C after LLL and L after CCC), as opposed to congruent (C after CCC and L after LLL) trials. For the alternating patterns (CLC/LCL), it was assumed that prediction accuracy will be higher and decision time will be lower in congruent trials (C after LCL and L after CLC), as opposed to their incongruent counterparts (C after CLC and L after LCL).

8.1.2 Research question 2

For sequences of repeating shots to the same direction (CCC and LLL), the length of the sequence was additionally considered as a factor. It was assumed that expectations towards the outcome of a subsequent shot will not only vary depending on the pattern, but also on how many successive shots to the same direction were previously played. Moreover, the direction in which balls were repeatedly directed to (cross-court vs. down-the-line) was hypothesized to make a difference here. Generally, cross-court shots occur with a higher frequency than down-the-line shots (e.g., Loffing & Hagemann, 2014a; Loffing, Hagemann, et al., 2010; Loffing, Sölter, et al., 2016). During match play, cross-court shot duels are occasionally played, meaning that both players are trying to chase their opponent out of the field by increasing the angle of ball flight. By suddenly switching the direction and playing a down-the-line shot they try to gain an advantage or even directly win the point. Therefore, it was assumed that for short sequence lengths (e.g., one previous shot) participants would rather expect a subsequent congruent shot (i.e., a cross-court shot after one previous cross-court shot). However, with increasing sequence length, the subjective probability of the participants for an (incongruent) shot to the other direction will increase (a down-the-line shot after one, two or three cross-court shots), resulting in higher prediction accuracies and faster decision times, respectively, in incongruent target trials as opposed to congruent target trials.

For repeated forehand down-the-line shots however, predictions are more difficult to make. Generally, down-the-line shots occur at a lower frequency when compared to cross-court shots (e.g., Loffing, Hageman, & Strauss, 2010; Martinez-Gallego, Guzman, James, et al., 2013; Martinez-Gallego, Guzman, Ramon-Llin, Crespo, & Vuckovic, 2013). Consequently, down-the-line-duels, i.e. several successive down-the-line shots from both players, occur quite infrequently. Therefore, it was assumed that participants would expect a change of direction immediately following the play of a down-the-line shot, resulting in higher prediction accuracies and lower decision times in incongruent trials as opposed to congruent ones. With regard to whether or not sequence length may influence the expectations, the formulation of a distinct a priori hypothesis remains difficult.

In addition, skilled tennis players and novices were included in the testing to determine whether the size of a sequential effect varies as a function of skill. The existing literature delivers contradictory findings regarding this issue. On the one hand, skilled athletes seem more susceptible to contextual cues when compared to less skilled or novice athletes (e.g., Farrow & Reid, 2012; Loffing & Hagemann, 2014a). On the other hand, patterns in previous event outcomes may be a very obvious cue that is considered by both skilled and unacquainted observers. In accordance to the findings of Loffing et al. (2015), the results from Study 2 suggest that both skilled tennis players and novices use the outcome of previous events to form their expectations towards a subsequent action. However, it must be noted that (1) the serve, which was the object of investigation in Study 2, clearly depicts a different situation than a rally, and (2) that novice athletes may lack the knowledge associated with the aforementioned specifics of tactical play in tennis. Therefore, a clear-cut a priori prediction as to which skill group would be more induced by patterns of previous outcomes was again difficult to make. Therefore, this portion of the study was considered as exploratory in nature and was conducted with the intent of moving towards a broader understanding of the possible skill effects apparent in contextual cue usage for action outcome anticipation.

8.2 Method

The experiment was approved by the local ethics committee at the Department of Social Science of the University of Kassel (E05201701).

8.2.1 Participants

Twenty-seven experienced tennis players (age: *M* = 26.85 years, *SD* = 5.74; 14 females) and thirty novice (age: *M* = 25.03 years, *SD* = 2.62; 15 females) voluntarily took part in the experiment. All participants were right-handed and reported normal or corrected-to-normal vision (two of the participants reported non-corrected vision; however, they reassured the experimenter that they were not impaired while watching the videos on the computer screen). At the time of testing, experienced tennis players reported to practice *M* = 3.15 hours (*SD* = 1.19) per week[13]. On average, experienced tennis players took part in *M* = 11.20 (*SD* = 5.81) tournaments or team competitions a year. Tennis players had *M* = 19.37 years (*SD* = 5.01) overall playing experience and their highest competition level ever played was third or sixth league in Germany. Six players reported that they have taken part in international tournaments. The mean Leistungsklasse (official ranking of the German tennis association [DTB]; ranking from 1 (best) – 23 (worst) based on match results in official competitions in the previous season) was 9.26 (*SD* = 2.89), the mean highest Leistungsklasse ever had was 8.00 (*SD* = 3.23). Novices had no experience in competitive tennis. Only one reported that he had played three years of competitive tennis in his youth. Seventeen novices reported that they have played tennis a few times, e.g., during university education, leisure time or schooling.

All participants were naïve as to the purpose of the study and written informed consent approval was obtained prior to testing.

8.2.2 Apparatus and stimuli

For the video material, single shots, as well as controlled and uncontrolled rallies between two right-handed tennis players were recorded using a digital camera (SONY HDR-FX1000). The camera was positioned on a tripod at a height of 1.5 m in the middle of the tennis court, shortly behind the service line. One player acted as return player behind the camera, while the other player's actions were recorded (see Fig. 28).

[13] Please note that the testing was conducted during the winter season, in which most of the players reported to only practice half as much as in the summer time.

The filmed player was an experienced, right-handed, male tennis player, 29 years of age. His official Leistungsklasse was LK 7 and he held an official coaching license of the German Tennis Association (DTB). The player behind the camera was an experienced, right-handed, female tennis player (LK 13), 21 years old, with 15 years of experience in competitive tennis. Prior to recording, both players provided written informed consent as to their participation.

A B

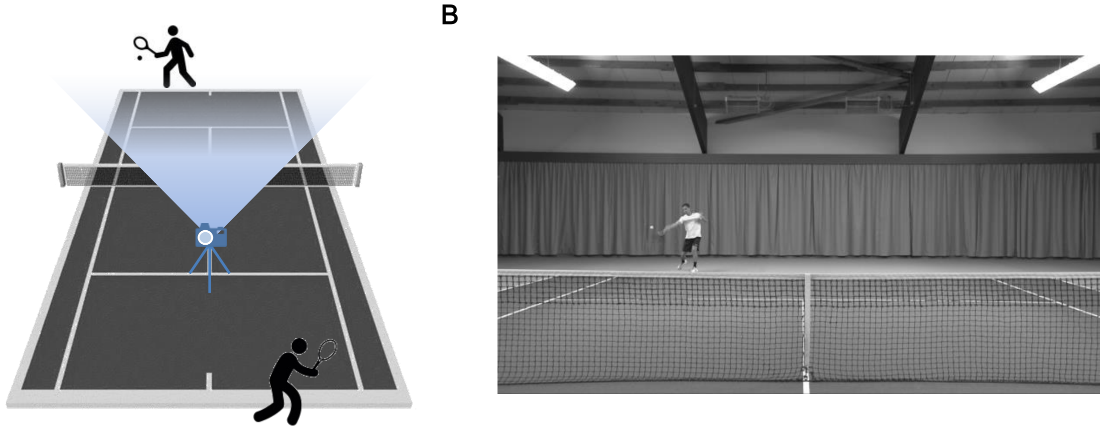


Fig. 28 **A.** Installation during the video recordings **B.** Detail screen from the raw video material showing a forehand baseline shot.

As to realize the study aim, several considerations had been made in advance to the video recordings. First, the study sought to examine the effect of different patterns in rallies on subsequent shots. This requires that rallies containing different shot patterns (e.g., all cross-court, all down-the-line, or alternating shots) are recorded and later combined with identical shots (target trials) to control for movement kinematics. Thereby, different types of target trials had to be recorded, as they should either be congruent (e.g., a target shot directed cross-court after CCC) or incongruent (e.g., a target shot down-the-line after CCC) with a previous pattern. Moreover, depending on where the last ball of the controlled rally was directed (e.g., to the right side of the return player), the ball entering the display right before the target shot must come from the same direction. This is important as video clips will be combined at the point of racket-ball contact of the return player behind the camera and varying ball flight will lead to anomalies in the artificially created rallies. Furthermore, as target trials should be presented as either first, second, third or fourth shot in a rally, this would lead to different lengths of the rallies which are later presented to the participants. To overcome this problem, another video clip of three shots must follow the target trial, so that each presented rally in the end contains four shots of the opponent, no matter if the target shot is presented as first, second, third or fourth shot in the rally.

Additionally, only patterns in repeated forehand baseline shots should be considered, to (1) eliminate an additional factor and (2) limit the number of overall experimental trials.

Based on these considerations, three types of video recordings were made:

(1) Video recordings containing controlled rallies with three successive shots of the filmed player: The return player behind the camera started the rally and played the first ball to the right of the filmed player. The filmed player was instructed to play either (1) three successive forehand cross-court shots to the right of the return player [CCC], (2) three successive forehand down-the-line shots to the left of the return player [LLL], or (3) to distribute the balls in an alternating pattern [CLC, LCL]. The return player was asked to simply return each ball to the right side of the filmed player. For each pattern, 10 recordings were made which only included valid strokes (i.e. those that landed within the single court limits). Afterwards, four rallies of each type were chosen for further video editing.

(2) Video recordings containing only single forehand baseline shots: Again, the return player behind the camera started the rally and played the first ball to the right of the filmed player. Balls were either played from the right side of the court or the left side, so the ball entered the visual display either from the right or the left. Four different versions of shots were then recorded (see Fig. 29):

V1: Forehand cross-court shot; the ball entered the visual scene from the right (played by the return player; blue line) and was sent back to the right (i.e. cross-court shot) by the filmed player (pink line; see Fig. 29A)

V2: Forehand down-the-line shot; the ball entered the visual scene from the right (played by the return player; blue line) and was sent back to the left (i.e. down-the-line shot) by the filmed player (pink line; see Fig. 29B)

V3: Forehand cross-court shot; the ball entered the visual scene from the left (played by the return player; blue line) and was sent back to the right (i.e. cross-court shot) by the filmed player (pink line; see Fig. 29C)

V4: Forehand down-the-line shot; the ball entered the visual scene from the left (played by the return player; blue line) and was sent back to the left (i.e. down-the-line shot) by the filmed player (pink line; see Fig. 29D)

For each version, 10 different shots were recorded and one of each type was later selected as *target trial*.

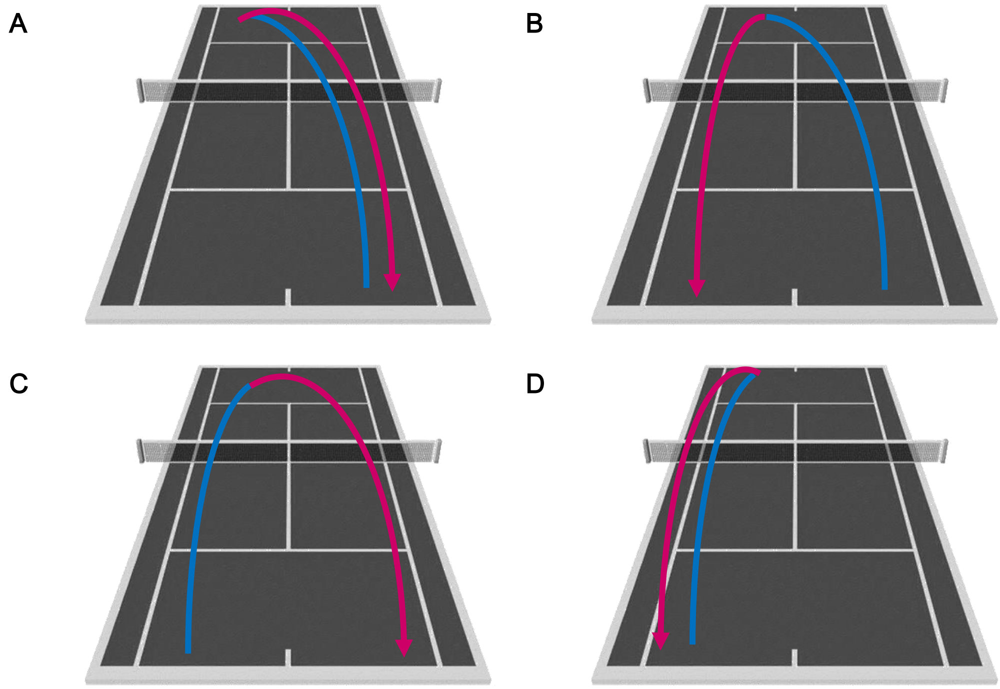


Fig. 29 Four different versions of single forehand baseline shots recorded during the creation of stimulus material, later serving as target trials.

(3) Video recordings containing *uncontrolled rallies*: Again, the return player behind the camera started the rally and played the first ball. First balls were played from the right or left side of the court. No specifications were made for shot direction. The players were asked to play as if they were in a real match, however, each rally should contain at least three baseline-shots of the filmed player. No further instructions were given. Approximately 20 different rallies were filmed, however, only a few were chosen for further video-editing.

Following the video recordings, single shots as well as controlled and uncontrolled rallies were chosen for further editing. In order to consistently evaluate the recordings a set of eligibility criteria was established which maintained that all shots were valid, that the shots were played with a certain velocity comparable to those played in competitions, and that shot movements of the filmed player did not contain any anomalies (e.g., an untypical posture). The selected video recordings were then edited using the video software Adobe Premiere Pro CS4.

Overall, 24 artificial rallies were created by combining clips of the three different types of original video recordings (see Fig. 30). They were cut together as follows: Three controlled shots which followed a certain pattern (CCC, LLL, CLC / LCL) were combined with one identical (and suitable) target trial and three shots from the uncontrolled rallies, which did not follow a specific pattern. Thus, each of the resulting artificial rallies contained seven shots of the filmed player. By embedding an identical target shot, kinematic cues were controlled in order to isolate potential sequential effects on anticipatory behavior in these trials. The combination of the three different video clips was configured in a way which ensured that the resulting rally ran as fluently as possible and that the cut-together was not noticed by the participants.

	Rally (controlled)			target stroke	Rally (uncontrolled)		
Original	**FH cross**	**FH cross**	**FH cross**	**FH longline**	**BH cross**	**BH cross**	**FH cross**

Fig. 30 Cut-together of an "artificial" rally for the experiment. With the help of video-editing software a controlled rally following a certain pattern (here: forehand cross-court/cross-court/cross-court) is combined with an identical target shot (here: forehand down-the-line) and a random rally.

For each pattern (CCC, LLL and CLC / LCL), four different controlled rallies were combined with a congruent (cross-court after CCC or LCL, down-the-line after LLL or CLC) and incongruent (down-the-line after CCC or CLC, cross-court after LLL or CLC) target trial, resulting in 3 (patterns) x 4 (repetitions) x 2 (target trials) = 24 different rallies. Uncontrolled rallies were attached in piecemeal fashion.

Each of the 24 rallies was presented under four different conditions, which varied in the position where the *target trial* was presented (see Fig. 31). This was realized by presenting four different cutouts of each rally, showing either (1) the target trial as fourth shot, with three previous shots of the opponent and no following shot, (2) the target trial as third shot, with two previous shots and one following shot, (3) the target trial as second shot, with one previous shot and two following shots or (4) the target trial as first shot, with no previous shots and three following shots.

	Rally (controlled)			target stroke	Rally (uncontrolled)		
Original	**FH cross**	**FH cross**	**FH cross**	**FH longline**	**BH cross**	**BH cross**	**FH cross**
L1	FH cross	FH cross	FH cross	FH longline	BH cross	BH cross	FH cross
L2	FH cross	FH cross	FH cross	FH longline	BH cross	BH cross	FH cross
L3	FH cross	FH cross	FH cross	FH longline	BH cross	BH cross	FH cross
L4	FH cross	FH cross	FH cross	FH longline	BH cross	BH cross	FH cross

Fig. 31 Details of the created stimuli. The "original" rally, containing a cut-together of a controlled rally, an identical target trial and an uncontrolled rally. This rally is presented under four different conditions (L1-L4) in which the presented cutout and hence, the position of the target trial is varied (three, two, one or no preceding shot).

Altogether, this resulted in 96 different rallies, which were shown to the participants twice in two consecutive blocks of 96 trials each. Thus, overall participants watched 192 rallies with each rally containing four shots of an opposing player. The size of each video was 1280 x 720 pixels (width x height). The experiment was programmed with the software Experiment Builder provided by SR Research.

8.2.3 Procedure

Participants individually took part in the study. Prior to the experiment participants were provided with standardized written instructions and were asked to fill out the first part of a questionnaire which included, amongst others, questions on demographic details and experience in tennis.

For the experiment, participants then watched 192 videos of tennis rallies on a 15'' notebook monitor from a seated position (eye-to-screen distance approximately 60 cm). For each shot in a rally, videos were occluded at racket-ball-contact. Subjects were asked to predict the shot direction as accurately and quickly as possible by pressing either the 'left CTRL' button (prediction of shot directed at a returning player's left side/backhand) or the 'delete Num-Pad' button (prediction of shot directed at a returning player's right side/forehand) on a German QWERTZ keyboard. The buttons were marked so they showed the letter 'L' or 'R' respectively. Before the start of the experimental trials, participants completed one practice rally containing four shots to familiarize themselves with the task. The rally presented as practice trial was not included in the experimental trials. After reassuring that the participants fully understood the task, the experimental trials commenced. The 96 rallies in the first block were presented in a random order (which differed across participants) determined by the experimental software. In the second block, the same videos were shown again, while the order generated in block 1 was maintained. For each shot and button press, respectively, the participants were provided with feedback on the effective shot direction after having made a prediction. Feedback was provided via presenting the off-cut of the video, starting at the occlusion point and ending again at the next racket-ball-contact of the filmed player, or with the ball leaving the display on the left or right edge for the last shot in each rally. The provision of feedback was necessary to enable the examination of the effect of previous shot outcomes and their sequence on expectation bias in prediction performance in target trials. This method gave the participants the feeling of virtually playing against the opponent.

After the first block (i.e., 96 rallies), participants were instructed to take a break of at least one minute (as ensured by the experimental software) before continuing with the second block.

Following the experiment, participants were asked to fill out the second half of the aforementioned questionnaire which now included questions regarding the course of the experiment. These included five questions, amongst others, aimed at identifying whether or not the participants were aware of the experiment's video manipulation:

- Question 1: Did you recognize any specific features regarding the course or the content of the presented videos?
- Question 2: If 'yes', please describe these specific features in the following.
- Question 3: Did you have the feeling that, in the experiment, identical rallies were presented multiple times? (Yes/No)
- Question 4: Did you have the feeling that particular patterns or regularities were present in the sequence of shot directions within the rallies, which allowed identifying shot outcomes? (Yes/No)
- Question 5: If 'yes', please describe these patterns or regularities in the following.

Altogether, the whole testing took about 75 min.

8.2.4 Data analysis

The dependent variables analyzed during this study included prediction accuracy and response time. Prediction accuracy was calculated by determining the percentage of correct shot direction predictions, while response time was calculated by determining the time difference (in milliseconds) between the opponent's racket-ball-contact and the moment of participant's key press (please note that response time could also assume negative values, when participants pressed the key before the racket-ball-contact). To calculate response times for each participant under each of the experimental conditions, the median was used to circumvent the distortion of the results by potential outliers.

With respect to the analysis of anticipatory performance in non-target trials, prediction accuracy and response time was calculated across all non-target trials. Anticipatory performance of experienced tennis players and novices was compared by means of t-tests for independent samples. Additionally, for target and non-target trials one sample t-tests were ran to determine whether or not both groups performed different from chance (50% prediction accuracy). For baseline target trials (shown as first shot in a rally), mean prediction accuracy and median response times were calculated across all trials, while tennis players' and novices' performance was compared using t-tests for independent samples.

All analyses were conducted using IBM SPSS Statistics 24. Alpha was set at .05 and partial eta-squared values were calculated as effect size measure for ANOVA. Exploratory Software for Confidence Intervals (ESCI) was used for the calculation of Cohen's d_{unb} (an unbiased estimate of the population effect size δ) and 95 % confidence intervals (see Cumming, 2012, for details).

8.2.4.1 Research question 1

With respect to the analysis of anticipatory performance in target trials presented as fourth shot in a rally, data was differentiated according to the two experimental factors which were *Congruence* and *Pattern of previous outcomes* in shots 1 to 3 (i.e. only cross-court shots, only down-the-line shots, and alternating patterns). Congruence refers to whether the shot direction in a target trial was congruent with the pattern in the sequence of the previous shot directions (i.e., a cross-court shot to the right following three cross-court shots or LCL or a down-the-line shot following three down-the-line shots or CLC) or not (incongruent: a cross-court shot to the right following three down-the-line shots or CLC or a down-the-line shot to the left following three cross-court shots or LCL). To check for overall effects in the dependent measures, for percentage of correct side prediction and response time, data was separately subjected to two 2 (Skill) x 3 (Pattern) x 2 (Congruence) mixed ANOVAs with skill as between-subjects factor and repeated measures on the last two factors.

8.2.4.2 Research question 2

With respect to the analysis of anticipatory performance in target trials presented as second, third or fourth shot in a rally with identical shot directions (C / CC / CCC and L / LL / LLL), data was differentiated according to the following three experimental factors: *Length of the sequence, Congruence* and *Pattern* in shot 1, 1 to 2 or 1 to 3 (i.e., only cross-court shots or only down-the-line shots). To check for overall effects in the dependent measures, for percentage of correct side prediction and response time, data was separately subjected to two 2 (Skill) x 3 (Length) x 2 (Pattern) x 2 (Congruence) mixed ANOVAs with skill as between-subjects factor and repeated measures on the last three factors.

8.3 Results

8.3.1 Manipulation check

To identify whether or not the participants were aware of the video manipulation, they were asked specific questions (see 6.2.3) in a post-experimental questionnaire. Out of a total of 57 participants, 19 novices and 19 tennis players reported that they had recognized specific features regarding the course or the content of the presented videos. Most of them reported that they felt identical rallies were presented multiple times, correspondingly, 55 of the 57 participants answered 'YES' to the question "Did you have the feeling that, in the experiment, identical rallies were presented multiple times?". However, only one tennis player wrote that they had the feeling that the rallies were partly cut together and no "real" rallies were presented, while none of the other participants seem to have detected the video manipulation. Regarding the question of whether or not a participant had the feeling that particular patterns or regularities were present in shot sequences, 30 participants answered with ‘YES’. However, most of them could not describe the patterns at all or they described regularities which were actually not present. 10 participants detected that patterns of repeating shot directions (four times cross-court or down-the-line) occurred several times and two reported that they noticed alternating patterns. All data was included in the analysis.

8.3.2 Research question 1

To address the first research question and examine the effect of patterns in previous shot direction on anticipatory performance in target trials presented as fourth shot in a rally, a 2 (Skill) x 3 (Pattern) x 2 (Congruence) ANOVA for the dependent variable prediction accuracy was carried out. Additionally, a 2 (Skill) x 3 (Pattern) x 2 (Congruence) ANOVA for the dependent variable response time was carried out. Next to prediction accuracy, response time is assumed to be a meaningful measure of anticipatory performance.

8.3.2.1 Prediction accuracy

The 2 (Skill) x 3 (Pattern) x 2 (Congruence) ANOVA revealed main effects for the following factors: *Skill*, $F(1, 55) = 20.372$, $p < .001$, $\eta_p^2 = .27$, *Pattern*, $F(2, 110) = 33.184$, $p < .001$, $\eta_p^2 = .376$, and *Congruence*, $F(1, 55) = 26.639$, $p < .001$, $\eta_p^2 = .326$.

Skilled tennis players were significantly more accurate (*M* = 76.56%, *SD* = 12.23%) than novices (*M* = 60.73%, *SD* = 10.71). Regarding the patterns presented in the previous three shots, further examination through pairwise comparisons showed that prediction accuracy was higher in target trials that followed the pattern CCC (*M* = 76.75%, *SD* = 18.82%) as opposed to the alternating pattern CLC / LCL (*M* = 69.05%, *SD* = 15.90%), $t(56) = 3.562$, $p = .001$, $d_{unb} = 0.39$, 95% CI [0.17, 0.63], and the pattern LLL (*M* = 60.53%, *SD* = 17.37%), $t(56) = 7.568$, $p < .001$, $d_{unb} = 0.88$, 95% CI [0.61, 1.18]. Additionally, prediction accuracy in target trials following the pattern CLC / LCL was higher than in target trials following the pattern LLL, $t(56) = 4.98$, $p < .001$, $d_{unb} = 0.55$, 95% CI [0.31, 0.80]. Irrespective of skill and pattern, prediction accuracy was higher in target trials that were congruent with a previous pattern (*M* = 75.15%, *SD*= 15.69%) as opposed to incongruent target trials (*M* = 62.94%, *SD* = 19.09%), *t*(56) = 5.23, *p* < .001, d_{unb} = 0.69, 95% CI [0.40, 0.99].

The ANOVA also revealed a significant *Pattern* x *Congruence* interaction, *F*(1.761, 96.829) = 22.57, *p* < .001, η_p^2 = .291. Visual inspection of Fig. 32 and further analysis through pairwise comparisons showed that prediction accuracy in target trials that were congruent, as opposed to incongruent, with a previous pattern did not significantly differ for the patterns CCC and alternating patterns CLC / LCL. However, for three successive down-the-line shots, prediction accuracy in subsequent target trials that were congruent (i.e., down-the-line) with the previous pattern (*M* = 77.85%, *SD* = 17.36%) was significantly higher than in target trials that were incongruent (i.e., cross-court) with the preceding pattern (*M* = 43.20%, *SD* = 29.03%), *t*(56) = 7.95, *p* < .001 d_{unb} = 1.43, 95% CI [1.00, 1.89] (see Fig. 32). For congruent target trials, prediction accuracy following an alternating pattern (CLC / LCLC, *M* = 69.08%, *SD* = 23.99%) was lower as opposed to target trials following the patterns CCC (*M* = 78.51%, *SD* = 20.42%), *t*(56) = 2.741, *p* = .009, d_{unb} = 0.42, 95% CI [0.11, 0.74], and LLL (*M* = 77.85%, *SD* = 17.36%), *t*(56) = 2.638, *p* = .011, d_{unb} = 0.41, 95% CI [0.10, 0.74] (see Fig. 32). No differences were found between the patterns CCC and LLL. For incongruent target trials, prediction accuracy following the pattern LLL (*M* = 43.22%, *SD* = 29.03%) was significantly lower as opposed to target trials following the patterns CCC (*M* = 75.00%, *SD* = 26.52%), *t*(56) = 9.051, *p* < .001, d_{unb} = 1.13, 95% CI [0.82, 1.47], and CLC / LCL (*M* = 70.61%, *SD* = 21.19%), *t*(56) = 6.299, *p* < .001, d_{unb} = 1.06, 95% CI [0.69, 1.47]. No differences were found between the patterns CCC and the alternating pattern (see Fig. 32).

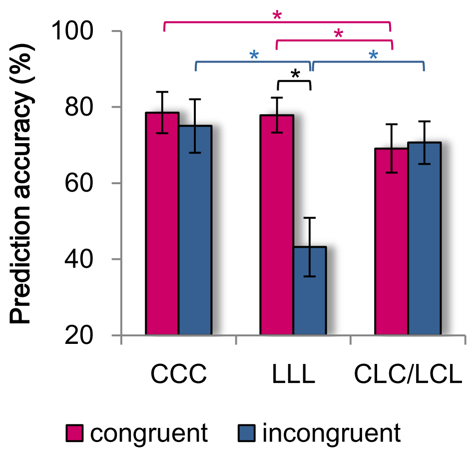


Fig. 32 Prediction accuracy (%) in congruent and incongruent target trials following the patterns CCC, LLL and CLC / LCL. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Lastly, the ANOVA revealed a significant *Pattern* x *Congruence* x *Group* interaction, $F(1.761, 96.829) = 5.067$, $p = .001$, $\eta_p^2 = .084$. To further examine the three way interaction, two separate 3 (Pattern) x 2 (Congruence) ANOVAs were calculated for novices and tennis players, respectively. The results are presented in Fig. 33.

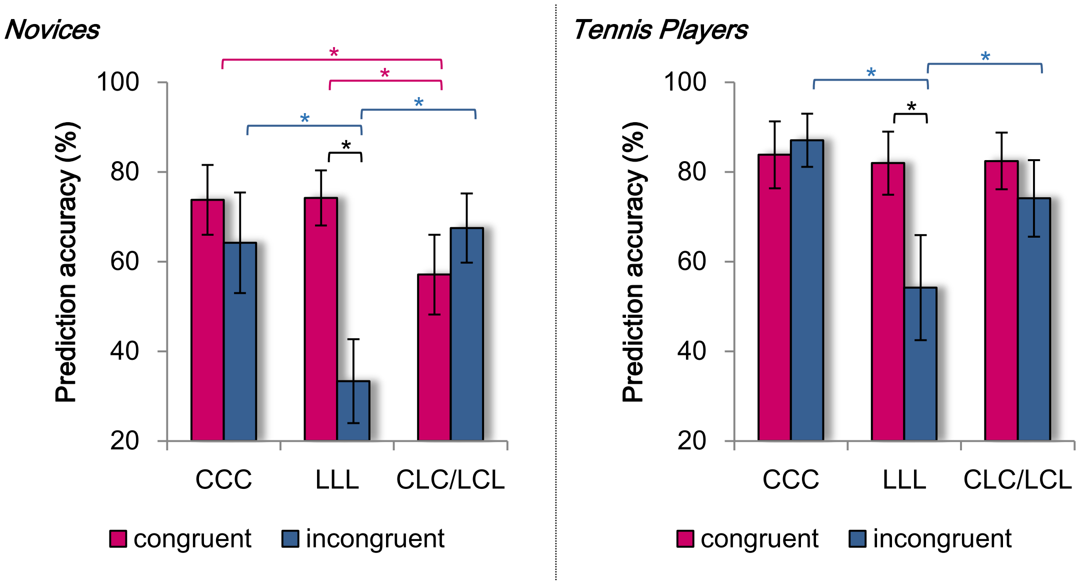


Fig. 33 Prediction accuracy (%) of novices and tennis players in congruent and incongruent target trials following the patterns CCC, LLL and CLC / LCL. Error bars represent 95%-confidence intervals, * ≙ p < .05.

For both groups, a significant *Pattern* x *Congruence* interaction was found, although the effect size was slightly bigger for novices, $F(1.729, 50.147) = 17.926$, $p < .001$, $\eta_p^2 = .382$, compared to tennis players, $F(2, 52) = 8.959$, $p < .001$, $\eta_p^2 = .256$. For novices, prediction accuracy following the pattern LLL was significantly higher in congruent target trials (M = 74.17%, SD = 16.39%) as opposed to incongruent target trials (M = 33.33%, SD = 25.07), $t(29) = 6.62$, $p < .001$, $d_{unb} = 1.87$, 95% CI [1.16, 2.67]. For the other patterns, no differences in prediction accuracies between congruent and incongruent target trials were found (see Fig. 33). Likewise tennis players showed differences in prediction accuracies between congruent (M = 81.94%, SD = 17.79%) and incongruent (M = 54.17%, SD = 29.62%) target trials following the pattern LLL, $t(26) = 4.645$, $p < .001$, $d_{unb} = 1.10$, 95% CI [0.56, 1.70], but not for the patterns CCC and CLC / LCL (see Fig. 33).

Regarding the prediction accuracy in congruent target trials, novices reached higher accuracies following the pattern CCC (M = 73.75%, SD = 20.85%), $t(29) = 3.01$, $p = .005$, $d_{unb} = 0.73$, 95% CI [0.22, 1.26], and LLL (M = 74.17%, SD = 16.39%), $t(29)$ =

3.496, p = .002, d_{unb} = 0.81, 95% CI [0.31, 1.34], as opposed to the alternating pattern CLC / LCL (M = 57.08%, SD = 23.83%). For incongruent target trials, prediction performance was worse after the pattern LLL (M = 33.33%, SD = 25.07%) as compared to patterns CCC (M = 64.17, SD = 30.04), t(29) = 6.251, p < .001, d_{unb} = 1.09, 95% CI [0.66, 1.56], and CLC / LCL (M = 67.50%, SD = 20.66%), t(29) = 5.674, p < .001, d_{unb} = 1.45, 95% CI [0.84, 2.12], see Fig. 33. Tennis players did not show differences in the prediction accuracy for congruent target trials depending on the pattern present in the previous three shots. However, for incongruent target trials, prediction accuracy for shots following the pattern CCC (M = 87.04%, SD = 14.90%) was significantly higher compared to shots following the patterns CLC / LCL (M = 74.07%, SD = 21.63%), t(26) = 2.608, p = .015, d_{unb} = 0.68, 95% CI [0.14, 1.25], and LLL (M = 54.17%, SD = 29.62%), t(26) = 6.461, p < .001, d_{unb} = 1.36, 95% CI [0.83, 1.96]. Further, prediction accuracy in incongruent target trials was higher following the pattern CLC / LCL compared to LLL, t(26) = 3.27, p = .003, d_{unb} = 0.75, 95% CI [0.26, 1.27], see Fig. 33.

None of the remaining main or interaction effects were statistically significant.

As data analysis revealed statistically significant differences in the baseline prediction accuracies for the four different target trials, another dependent variable was provided post-hoc, in order to overcome possible distortions in the results. Δ-prediction accuracy refers to the total difference between prediction accuracy in target trials presented as second, third or fourth shot in a rally and the corresponding prediction accuracy in target trials presented as first shot in a rally, with no preceding shots. Therefore, Δ-prediction accuracy can also assume negative values. While positive values indicate that prediction accuracy increases when a target trial is presented as second, third or fourth shot in a rally compared to when no preceding shots are shown, negative values indicate the opposite.

8.3.2.2 Δ-Prediction accuracy

The 2 (Skill) x 3 (Pattern) x 2 (Congruence) ANOVA revealed main effects for the factors *Pattern*, F(2, 110) = 3.585, p = .031, η_p^2 = .061, and *Congruence*, F(1, 55) = 11.056 p = .002, η_p^2 = .167, a significant *Pattern* x *Congruence* interaction, F(2, 110) = 3.701, *p* = .028, η_p^2 = .063, and a *Pattern* x *Congruence* x *Group* interaction, *F*(2, 110) = 4.655, *p* = .011, η_p^2 = .078.

Regarding the patterns present in the previous three shots, further examination through pairwise comparisons and visual inspection of Fig. 34A showed that prediction accuracy was descriptively higher compared to baseline target trials in target trials that followed the pattern CCC (*M* = 2.27%, *SD* = 14.36%) and the alternating pattern CLC / LCL (*M* = 0.78%, *SD* = 12.77%), while it was lower compared to baseline target trials following the pattern LLL (*M* = -3.14%, *SD* = 13.17%). Differences were significant between patterns CCC and LLL, *t*(56) = 2.291, *p* = .026, d_{unb} = 0.39, 95% CI [0.05, 0.74]. Irrespective of skill and pattern, prediction accuracy was higher compared to baseline target trials in target trials that were congruent with a previous pattern (*M* = 4.55%, *SD* = 12.87%) as opposed to incongruent target trials, where prediction accuracy was lower compared to baseline target trials (*M* = -4.22%, *SD* = 13.80%), *t*(56) = 3.781, *p* < .001, d_{unb} = 0.65, 95% CI [0.29, 1.02] (see Fig. 32B).

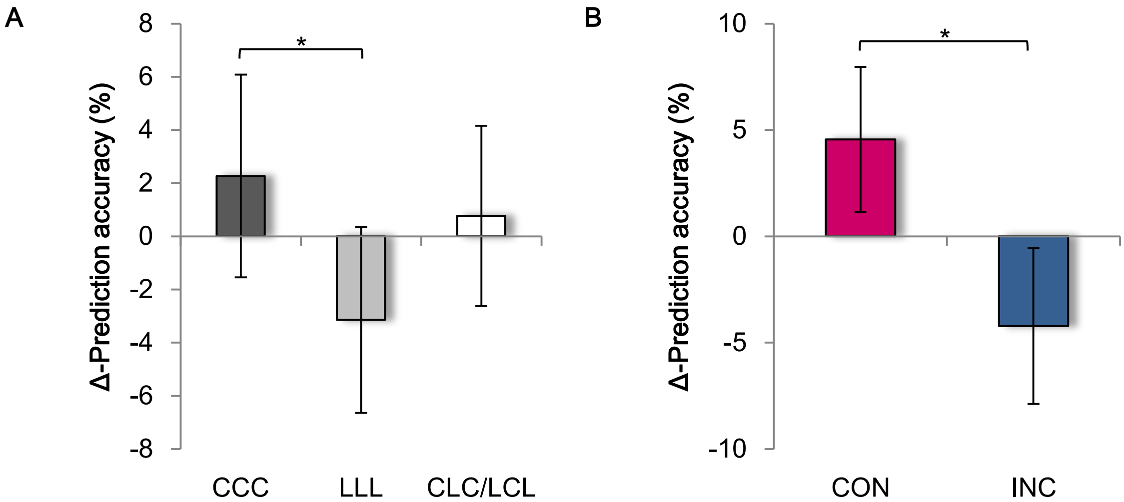


Fig. 34 **A.** Δ-Prediction accuracy (%) in target trials following the patterns CCC, LLL and CLC/LCL. **B.** Δ-Prediction accuracy (%) in congruent and incongruent target trials following three repeated shots in the same direction. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Visual inspection of Fig. 35 (overall) and further analysis through pairwise comparisons show that Δ-prediction accuracy in target trials that were congruent, as opposed to incongruent, with a previous pattern did not significantly differ for the pattern CCC. However, for three successive down-the-line shots, prediction accuracy in subsequent target trials, that were congruent (i.e., down-the-line) with the previous pattern, was higher compared to baseline target trials (M = 4.90%, SD = 23.20%) and differed significantly from incongruent (i.e., cross-court) target trials, for which prediction accuracy was lower compared to baseline target trials (M = -11.18%, SD = 27.57%), $t(56) = 2.783$, p = .007 d_{unb} = 0.62, 95% CI [0.17, 1.09]. Likewise, for the alternating pattern CLC / LCL, Δ-prediction accuracy differed between congruent (M = 6.36%, SD = 20.40%) and incongruent target trials (M = -4.82%, SD = 21.02%), $t(56) = 2.589$, p = .012, d_{unb} = 0.53, 95% CI [0.12, 0.96]. For congruent target trials, no differences were found between the three patterns. For incongruent target trials, Δ-prediction accuracy differed significantly between the patterns CCC and LLL, $t(56) = 2.946$, p = .005, d_{unb} = 0.56, 95% CI [0.17, 0.96]. While the CCC pattern produced a prediction accuracy in incongruent target trials that was higher compared to baseline target trials (M = 3.95%, SD = 25.79%) the LLL pattern produced the opposite case (M = -11.18%, SD = 27.57%).

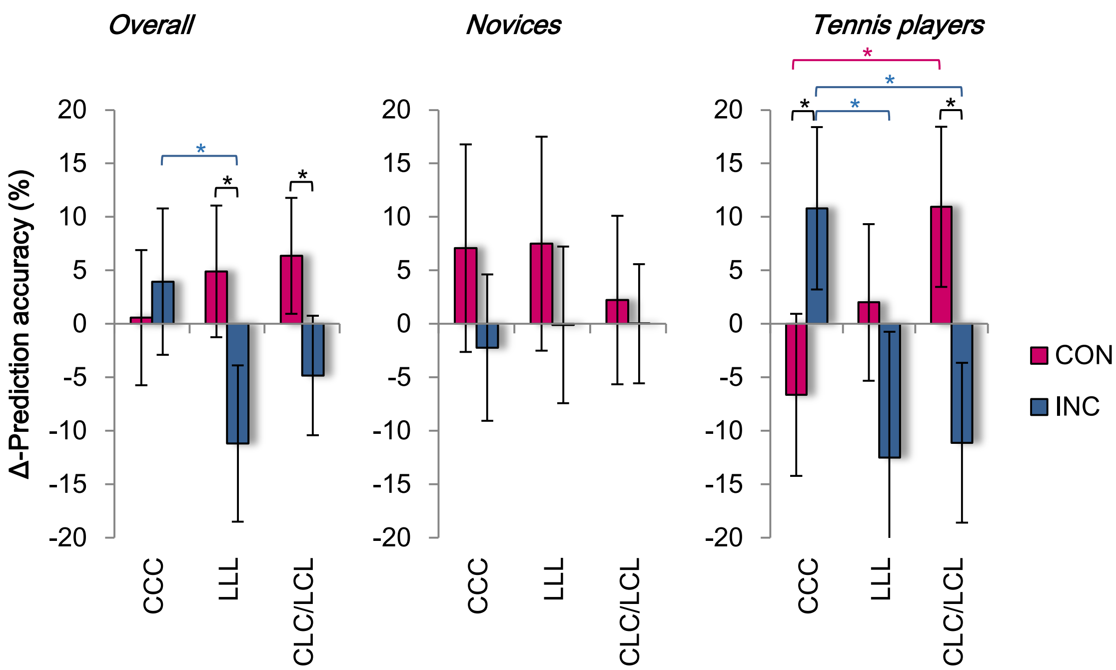


Fig. 35 Δ-prediction accuracy in congruent and incongruent target trials compared to the corresponding baseline target trials (presented as 1st shots in a rally with no preceding pattern). Negative values indicate a higher accuracy in baseline target trials compared to target trials at 4th position, and vice versa. Error bars represent 95%-confidence intervals, * ≙ p < .05.

To further examine the three way interaction, two separate 3 (Pattern) x 2 (Congruence) ANOVAs were calculated for novices and tennis players, respectively. The results are presented in Fig. 35.

A significant *Pattern* x *Congruence* interaction was found for tennis players only, $F(2, 52) = 9.212$, $p < .001$, $\eta_p^2 = .262$. For the pattern CCC, Δ-prediction accuracy differed significantly between congruent (M = -6.64%, SD = 19.14%) and incongruent target trials (M = 10.80%, SD = 19.21%), $t(56) = 3.270$, $p = .003$, $d_{unb} = 0.88$, 95% CI [0.30, 1.50]. While prediction accuracy in incongruent target trials (i.e., down-the-line after CCC) was higher compared to when no preceding shots were shown, prediction accuracy in congruent target trials (i.e., cross-court after CCC) was lower compared to baseline target trials. For the other two patterns (LLL and CLC / LCL, respectively), prediction accuracy was higher compared to baseline target trials in congruent target trials and lower in incongruent target trials. For the alternating pattern, a significant difference in Δ-prediction accuracy between congruent (M = 10.96%, SD = 18.92%) and incongruent target trials (M = -11.11%, SD = 18.88) was found, $t(26) = 4.008$, $p < .001$, $d_{unb} = 1.13$, 95% CI [0.51, 1.81]. Regarding the Δ-prediction accuracy in congruent target trials, significant differences were found between the pattern CCC (M = -6.64%, SD = 19.14%) and CLC / LCL (M = 10.96%, SD = 18.92%), $t(26) = 3.384$, $p = .002$, $d_{unb} = 0.90$, 95% CI [0.33, 1.51]. Moreover, Δ-prediction accuracy in incongruent target trials differed significantly between the patterns CCC (M = 10.80%, SD = 19.21%) and LLL (M = -12.50%, SD = 29.76%), $t(26) = 3.379$, $p = .002$, $d_{unb} = 0.90$, 95% CI [0.33, 1.52], as well as CCC and CLC / LCL (M = -11.11%, SD = 18.88%), $t(26) = 4.258$, $p < .001$, $d_{unb} = 1.12$, 95% CI [0.53, 1.76].

None of the remaining main or interaction effects were statistically significant.

8.3.2.3 Response time

The 2 (Skill) x 3 (Pattern) x 2 (Congruence) ANOVA revealed a main effect for *Pattern*, $F(2, 110) = 4.142$, $p = .018$, $\eta_p^2 = .07$, and a significant *Pattern* x *Congruence* interaction, $F(1.826, 100.43) = 6.111$, $p = .004$, $\eta_p^2 = .10$.

Response time in target trials that followed the pattern CCC (M = 177.30 ms, SD = 256.60 ms) was significantly lower than in target trials following the alternating pattern CLC / LCL (M = 235.32 ms, SD = 277.16 ms), $t(56) = 3.506$, $p = .001$, $d_{unb} = 0.21$, 95% CI [0.09, 0.34]. Response time in target trials following the pattern LLL was higher compared to target trials following the pattern CCC and lower compared to target trials following the pattern CLC / LCL. However, both differences failed to reach statistical significance (p = .074 and p = .057).

Visual inspection of Fig. 36 and further analysis through pairwise comparisons showed that differences in response times between congruent and incongruent target trials were present only for target trials following the pattern CCC. Participants responded faster in incongruent target trials (M = 150.04 ms, SD = 241.09 ms) as opposed to congruent target trials (M = 228.01 ms, SD = 354.40 ms), t(56) = 2.925, p = .005, d_{unb} = 0.25, 95% CI [0.08, 0.44]. For the other two patterns, mean response times were shorter for congruent target trials. However, differences failed to reach statistical significance. For congruent target trials, no differences in the response times subject to the three patterns could be revealed. However, participants responded faster in incongruent target trials when they followed the CCC pattern (M = 150.04 ms, SD = 241.09 ms) as opposed to LLL (M = 221.87 ms, SD = 271.00 ms), t(56) = 3.545, p = .001, d_{unb} = 0.28, 95% CI [0.12, 0.44], and CLC/LCL (M = 250.28 ms, SD = 283.26 ms), t(56) = 4.746, p < .001, d_{unb} = 0.38, 95% CI [0.21, 0.55], (see Fig. 36).

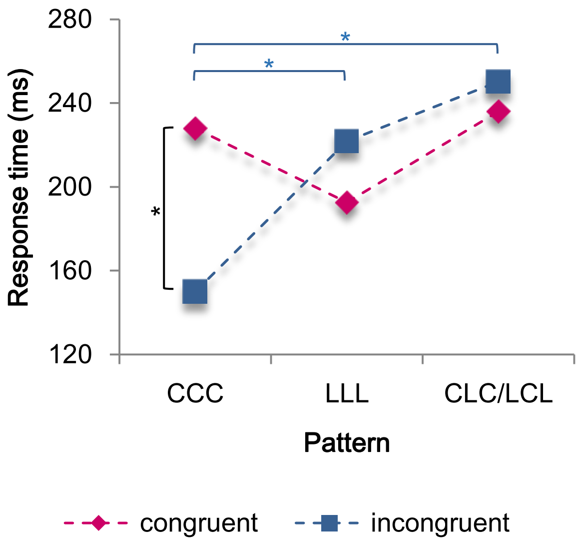


Fig. 36 Mean response time (ms) in congruent and incongruent target trials following the patterns CCC, LLL and CLC / LCL. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Overall, novices (M = 154.42 ms, SD = 257.64 ms) tended to respond earlier than tennis players (M = 262.00 ms, SD = 218.46 ms), however, no main effect for the between-subjects factor *Skill* was found, p = .084.

8.3.3 Research question 2

To address the second research question and examine the effect of pattern length on anticipatory performance in target trials presented as second, third or fourth shot in a rally, three separate 2 (Skill) x 3 (Length) x 2 (Pattern: cross-court vs. down-the-line) x 2 (Congruence) ANOVAs for prediction accuracy, Δ-prediction accuracy and response time were carried out. Again, the Δ-prediction accuracy variable created post-hoc, was integrated to overcome differences in baseline prediction accuracies.

8.3.3.1 Prediction accuracy

The 2 (Skill) x 3 (Length) x 2 (Pattern) x 2 (Congruence) ANOVA revealed main effects for the following factors: *Skill*, $F(1, 55) = 20.684$, $p < .001$, $\eta_p^2 = .27$, *Pattern*, $F(1, 55) = 92.047$, $p < .001$, $\eta_p^2 = .626$, and *Congruence*, $F(1, 55) = 108.817$, $p < .001$, $\eta_p^2 = .664$, as well as several two-way interactions.

Skilled tennis players were more accurate (*M* = 75.23%, *SD* = 12.62%) compared to novices (*M* = 61.32%, *SD* = 10.46), $t(55) = 4.548$, $p < .001$, $d_{unb} = 1.19$, 95% CI [0.64, 1.77]. Regarding the patterns present in the previous three shots, further examination through pairwise comparisons showed that prediction accuracy was higher in target trials that followed one, two or three successive cross-court shots [C / CC / CCC] (*M* = 74.49%, *SD* = 15.64%) as opposed to the down-the-line pattern [L / LL / LLL] (*M* = 61.33%, *SD* = 12.97%), $t(56) = 9.611$, $p = .001$, $d_{unb} = 0.90$, 95% CI [0.66, 1.17]. Irrespective of skill, length and pattern, prediction accuracy was higher in target trials that were congruent with a previous pattern, e.g. C after C / CC / CCC or L after L / LL / LLL (*M* = 81.80%, *SD* = 11.64%), as opposed to incongruent target trials, e.g. L after C / CC / CCC or C after L / LL / LLL (*M* = 54.02%, *SD* = 20.96%), $t(56) = 10.111$, $p < .001$, $d_{unb} = 1.62$, 95% CI [1.20, 2.07].

The ANOVA also revealed several two-way-interactions. First, a significant *Group* x *Congruence* interaction was found, $F(1, 55) = 6.294$, $p = .015$, $\eta_p^2 = .103$ (see Fig. 37A). Both groups reached higher prediction accuracies in congruent as opposed to incongruent target trials. However, the prediction accuracy for novices differed by 34.03% (*SD* = 22.09%) between congruent and incongruent target trials, $t(29) = 8.437$, $p < .001$, $d_{unb} = 2.18$, 95% CI [1.45, 3.00]. This difference was lower (*M* = 20.83%, *SD* =

16.95%) for skilled tennis players, $t(26) = 6.389$, $p < .001$, $d_{unb} = 1.33$, 95% CI [0.80, 1.92]. Regarding congruent target trials, prediction accuracies between tennis players ($M = 85.65\%$, $SD = 11.78\%$) and novices ($M = 78.33\%$, $SD = 10.53\%$), $t(55) = 2.476$, $p = .016$, $d_{unb} = 0.65$, 95% CI [0.12, 1.19], differed less as opposed to incongruent target trials, $t(55) = 4.203$, $p < .001$, $d_{unb} = 1.10$, 95% CI [0.55, 1.67], where prediction accuracy was 20.51% higher for tennis players.

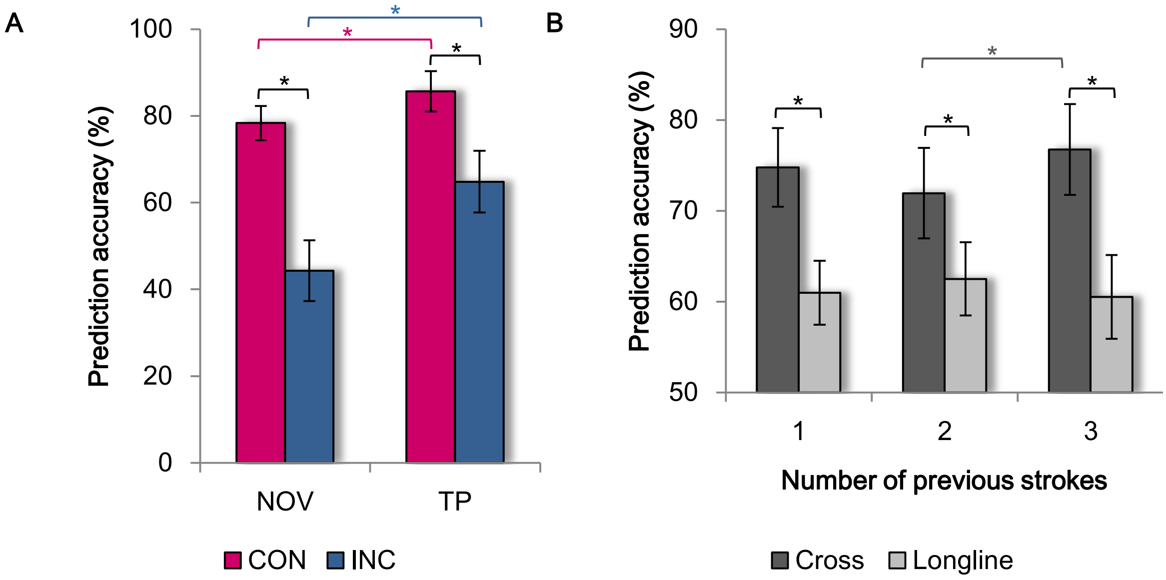


Fig. 37 A. Prediction accuracy (%) of novices and tennis players in congruent and incongruent target trials following repeated shots to the same direction. B. Prediction accuracy (%) in target trials after one, two, or three preceding shots, differentiated by pattern (cross-court vs. down-the-line). Error bars represent 95%-confidence intervals, * ≙ p < .05.

Second, a significant *Length* x *Pattern* interaction was found, $F(2, 110) = 3.582$, $p = .031$, $\eta_p^2 = .061$ (see Fig. 37B). For all three lengths (i.e., one, two or three preceding shots), prediction accuracy varied as a function of pattern. In general, prediction accuracy was higher in target trials that followed repeating cross-court shots (C / CC / CCC) compared to repeating down-the-line shots (L / LL / LLL). Differences were nearly equal for one preceding shot (C: $M = 74.78\%$, $SD = 16.32\%$; L: $M = 60.96\%$, $SD = 13.27$), $t(56) = 7.031$, $p < .001$, $d_{unb} = 0.93$, 95% CI [0.62, 1.24], and three preceding shots (CCC: $M = 76.75\%$, $SD = 18.82\%$; LLL: $M = 60.52\%$, $SD = 17.37\%$), $t(56) = 7.568$, $p < .001$, $d_{unb} = 0.88$, 95% CI [0.61, 1.18], and slightly less for two preceding shots (CC: $M = 71.93\%$, $SD = 18.75\%$; LL: $M = 62.50\%$, $SD = 15.17\%$), $t(56) = 4.855$, $p < .001$, $d_{unb} = 0.55$, 95% CI [0.31, 0.80]. For repeated down-the-line shots, no differences in prediction accuracy, as a function of pattern length, could be detected. However, for repeated cross-court shots, prediction accuracy in target trials that followed three successive cross-court shots (CCC, *M* = 76.75%, *SD* = 18.82%) was significantly higher than in target trials that followed two successive cross-court shots (CC, *M* = 71.93%, *SD* = 18.75%), *t*(56) = 2.084, *p* = .042, d_{unb} = 0.25, 95% CI [0.01, 0.50].

Third, a significant *Length* x *Congruence* interaction was found, *F*(2, 110) = 14.450, *p* < .001, η_p^2 = .208 (see Fig. 38A). Irrespective of length, prediction accuracy was higher for congruent as opposed to incongruent target trials. However, the difference decreased for increasing sequence length (see Tab. 7).

Tab. 7 *Comparison of prediction in congruent and incongruent target trials as a function of length of preceding sequence (L), by means of t-tests for matched pairs (two-tailed).*

L	*Pred. Acc. (%)*		*Diff. (%)*	*t-test for matched pairs (two-tailed)*
1	CON	85.75 [10.74]	35.75 [21.48]	*t*(56) = 12.563, *p* <.001, d_{unb} = 2.10
	INC	50.00 [31.16]		
2	CON	81.47 [15.80]	28.51 [26.09]	*t*(56) = 8.249, *p* <.001, d_{unb} = 1.39, 95% CI [0.98, 1.83]
	INC	52.96 [23.77]		
3	CON	78.18 [16.50]	19.08 [26.26]	*t*(56) = 5.485, *p* <.001, d_{unb} = 0.90, 95% CI [0.54, 1.28]
	INC	59.10 [24.22]		

For congruent target trials, prediction accuracy was higher when the target trials were preceded by only one (*M* = 85.75%, *SD* = 10.75%) as opposed to two (*M* = 81.47%, *SD* = 15.80%), *t*(56) = 2.133, *p* = .037, d_{unb} = 0.31, 95% CI [0.02, 0.61], or three shots (*M* = 78.18%, *SD* = 16.50), *t*(56) = 3.875, *p* < .001, d_{unb} = 0.54, 95% CI [0.25, 0.83]. For incongruent target trials, prediction accuracy was higher when the target trials were preceded by three (*M* = 59.10%, *SD* = 24.22%) as opposed to two shots (*M* = 52.96%, *SD* = 23.77%), *t*(56) = 2.655, *p* = .01, d_{unb} = 0.25, 95% CI [0.06, 0.45], or one shot (*M* = 50.00%, *SD* = 21.16%), *t*(56) = 4.004, *p* < .001, d_{unb} = 0.39, 95% CI [0.19, 0.61].

Fourth, a significant *Pattern* x *Congruence* interaction was found, *F*(1, 55) = 133.111, *p* <.001, η_p^2 = .708 (see Fig. 38B). For both patterns, prediction accuracy was higher in congruent than incongruent target trials. However, for repeated cross-court shots, the difference between congruent (*M* = 79.39%, *SD* = 15.89%) and incongruent target trials (*M* = 69.59%, *SD* = 22.56) was rather small, *t*(56) = 3.167, *p* = .002, d_{unb} = 0.50, 95% CI [0.18, 0.82], compared to repeated down-the-line shots (congruent: *M* = 84.21%, *SD* = 10.56%; incongruent: *M* = 38.45%, *SD* = 22.79%), *t*(56) = 14.239, *p* < .001, d_{unb} = 2.54. While prediction accuracy in congruent trials following repeated down-the-line shots (*M* = 84.21%, *SD* = 10.56%) was higher compared to prediction accuracy in congruent target trials following repeated cross-court shots (*M* = 79.39%, *SD* = 15.89%),

$t(56) = 2.667$, $p = .01$, $d_{unb} = 0.35$, 95% CI [0.09, 0.63], for incongruent trials the opposite was the case. Here, prediction accuracy was higher following repeated cross-court shots (M = 69.59%, SD = 22.56%) compared to repeated down-the-line shots (M = 38.45%, SD = 22.79%), $t(56) = 13.556$, $p < .001$, $d_{unb} = 1.36$, 95% CI [1.05, 1.69].

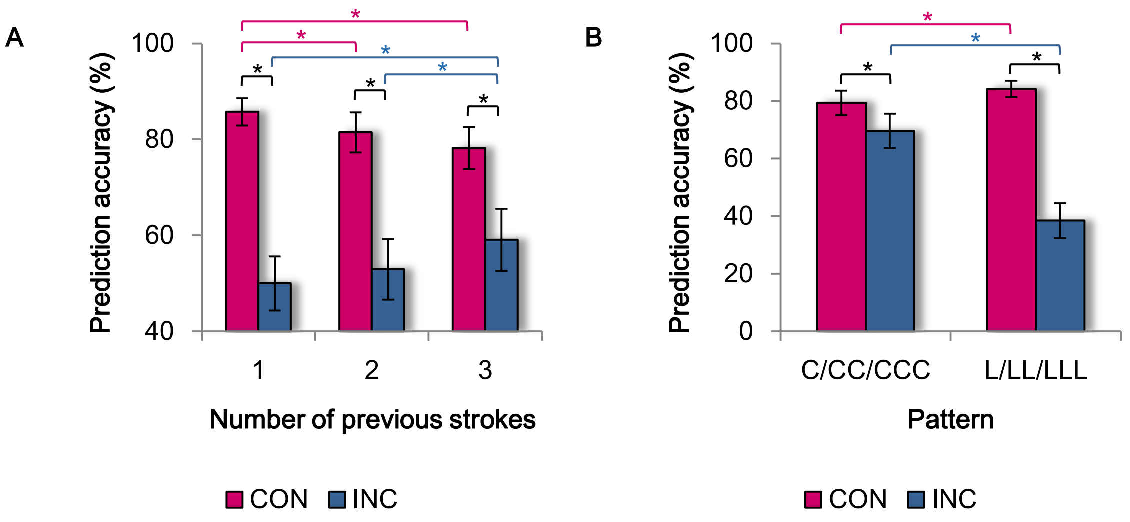


Fig. 38 **A.** Prediction accuracy (%) in congruent and incongruent target trials following repeated shots to the same direction as a function of number of previous shots. **B.** Prediction accuracy (%) in congruent and incongruent target trials differentiated by pattern (cross-court vs. down-the-line) and irrespective of pattern length. Error bars represent 95%-confidence intervals, * ≙ p < .05.

None of the remaining main or interaction effects were statistically significant.

8.3.3.2 Δ-Prediction accuracy

The 2 (Skill) x 3 (Length) x 2 (Pattern) x 2 (Congruence) ANOVA revealed a main effect for *Congruence*, $F(1, 55) = 26.705$, $p < .001$, $\eta_p^2 = .327$, as well as several two-way interactions.

Irrespective of pattern and length, Δ-prediction accuracy differed significantly between congruent and incongruent target trials. Prediction accuracy in target trials that were congruent with the previous pattern (i.e., C after C/CC/CCC and L after L/LL/LLL, respectively) was higher compared to baseline target trials (M = 6.36%, SD = 15.16%) while prediction accuracy in target trials that were incongruent with the previous pattern (i.e., C after L/LL/LLL and L after C/CC/CCC, respectively) was lower compared to baseline target trials (M = -8.70%, SD = 13.72%; see Fig. 39A).

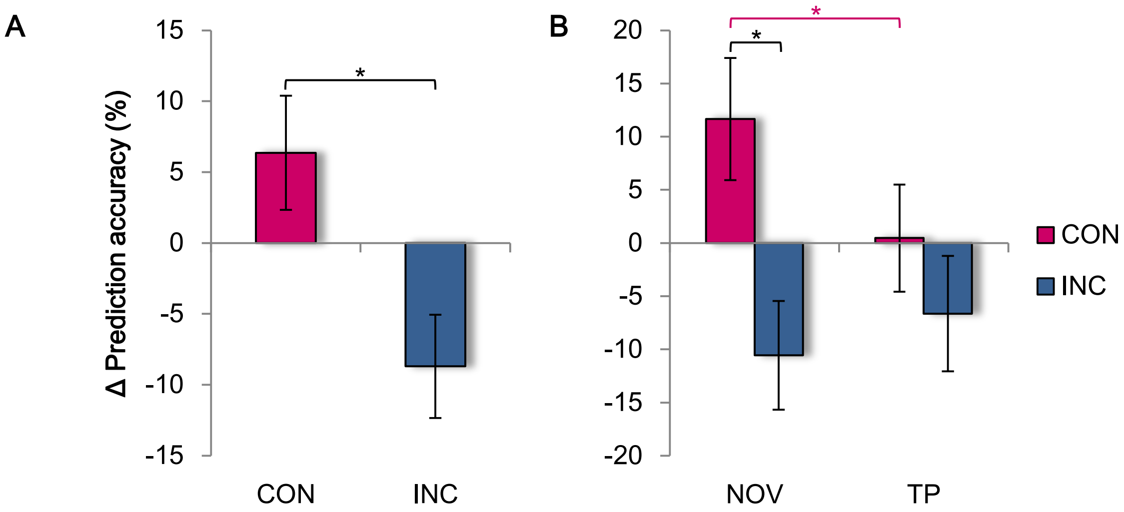


Fig. 39 **A.** Δ-Prediction accuracy (%) in congruent and incongruent target trials following repeated shots to the same direction. **B.** Δ-Prediction accuracy (%) of novices and tennis players in congruent and incongruent target trials following repeated shots to the same direction. Error bars represent 95%-confidence intervals, * ≙ p < .05.

The ANOVA also revealed several two-way-interactions:

First, a significant *Group* x *Congruence* interaction was found, $F(1, 55) = 7.105$, $p = .01$, $\eta_p^2 = .114$ (see Fig. 39B). While the Δ-prediction accuracy for novices differed significantly between congruent ($M = 11.67\%$, $SD = 15.38\%$) and incongruent target trials ($M = -10.56\%$, $SD = 13.66\%$) presented after one, two or three successive shots to the same side, $t(29) = 5.700$, $p < .001$, $d_{unb} = 1.49$, 95% CI [0.86, 2.17], no difference was found for tennis players. Furthermore, for congruent target trials, Δ-prediction accuracy was higher for novices ($M = 11.67\%$, $SD = 15.38\%$) compared to tennis players ($M = 0.46\%$, $SD = 12.76\%$), $t(55) = 2.974$, $p = .004$, $d_{unb} = 0.78$, 95% CI [0.25, 1.33]. No differences between the two groups were found for incongruent target trials.

Second, a significant *Length* x *Pattern* interaction was found, $F(2, 110) = 3.582$, $p = .031$, $\eta_p^2 = .061$ (see Fig. 40A). For repeated cross-court shots, Δ-prediction accuracy differed when target trials were presented after two ($M = -2.56\%$, $SD = 18.44\%$) as opposed to three ($M = 2.27\%$, $SD = 14.36\%$) preceding shots, $t(56) = 2.084$, $p = .042$, $d_{unb} = 0.29$, 95% CI [0.01, 0.57]. For target trials presented after two cross-court shots, prediction accuracy was lower compared to when no preceding shots were shown. For three cross-court shots, prediction accuracy was higher compared to baseline values. For repeated down-the-line shots, predictions were worse overall when compared to baseline target trials. Furthermore, no differences in Δ-prediction accuracy as a function of pattern length were found. For sequences of three shots, Δ-prediction accuracy varied as a function of pattern, $t(56) = 2.291$, $p = .026$, $d_{unb} = 0.39$, 95% CI [0.05, 0.74]. Δ-prediction accuracy was higher compared to baseline target trials for the pattern CCC ($M = 2.27\%$, $SD = 14.36\%$) and lower compared to baseline target trials for the pattern LLL ($M = -3.14\%$, $SD = 13.17\%$).

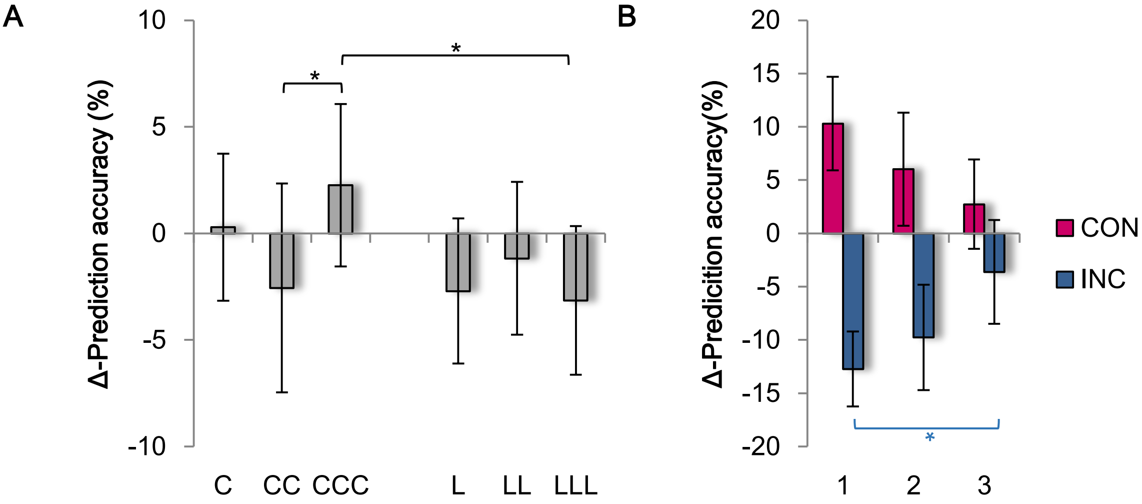


Fig. 40 **A.** Δ-Prediction accuracy (%) in target trials following one, two or three repeated shots to the same direction, differentiated by pattern. **B.** Δ-Prediction accuracy (%) in congruent and incongruent target trials following repeated shots to the same direction as a function of pattern length. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Third, a significant *Length* x *Congruence* interaction was found, $F(2, 110) = 14.450$, $p < .001$, $\eta_p^2 = .208$ (see Fig. 40B). With increasing sequence length, the difference between congruent and incongruent target trials decreased and both values approached zero. For target trials presented after only one preceding shot, a strong difference in Δ-prediction accuracy between congruent ($M = 10.31\%$, $SD = 16.53\%$) and incongruent ($M = -12.72\%$, $SD = 13.23\%$) target trials was found, $t(56) = 7.162$, $p < .001$, $d_{unb} = 1.52$, 95% CI [1.03, 2.04]. This difference decreased when target trials followed two previous shots to the same direction (congruent: $M = 6.03\%$, $SD = 19.98\%$; incongruent: $M = -9.76\%$, $SD = 18.59\%$), $t(56) = 4.368$, $p < .001$, $d_{unb} = 0.81$, 95% CI [0.42, 1.21]. For three repeated shots to the same direction, differences between congruent and incongruent target trials dissolved (see Fig. 9B).

For congruent target trials, Δ-prediction accuracy was higher when the target trials were preceded by only one ($M = 10.31\%$, $SD = 16.53\%$) as opposed to two ($M = 6.03\%$, $SD = 19.98\%$), $t(56) = 2.133$, $p = .037$, $d_{unb} = 0.23$, 95% CI [0.01, 0.45], or three shots (*M* = 2.74%, *SD* = 15.76), *t*(56) = 3.875, *p* < .001, d_{unb} = 0.46, 95% CI [0.21, 0.72]. For incongruent target trials, negative values for Δ-prediction accuracy were found irrespective of length. Moreover, the difference from prediction accuracy in baseline target trials was higher when the target trials were preceded by one (*M* = -12.72%, *SD* = 13.23%) as opposed to three (*M* = -3.62%, *SD* = 18.35%), *t*(56) = 4.004, *p* < .01, d_{unb} = 0.56, 95% CI [0.27, 0.86], or two (*M* = -9.76%, *SD* = 18.59%) as opposed to three shots, *t*(56) = 2.655, *p* = .01, d_{unb} = 0.33, 95% CI [0.08, 0.58] (see Fig. 40B).

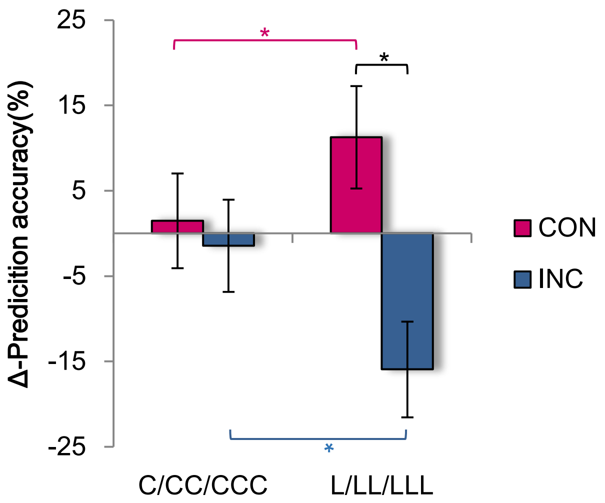


Fig. 41 Δ-Prediction accuracy (%) in congruent and incongruent target trials differentiated by pattern and irrespective of pattern length. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Fourth, a significant *Pattern* x *Congruence* interaction was found, *F*(1, 55) = 11.334, *p* = .001, η_p^2 = .171 (see Fig. 41). For both patterns, participants reached higher prediction accuracies compared to baseline target trials in target trials that were congruent with the previous pattern. In incongruent target trials, prediction accuracy was lower compared to baseline values. However, for repeated cross-court shots, the difference between congruent (*M* = 1.46%, *SD* = 20.89%) and incongruent target trials (*M* = -1.46%, *SD* = 20.34) regarding Δ-prediction accuracy was very small and failed to reach statistical significance. For repeated down-the-line shots, Δ-prediction accuracy clearly differed between congruent (*M* = 11.26%, *SD* = 22.64%) and incongruent target trials (*M* = -15.94%, *SD* = 21.16%), *t*(56) = 5.305, *p* < .001, d_{unb} = 1.22, 95% CI [0.72, 1.75]. For congruent trials Δ-prediction accuracy following repeated down-the-line shots (*M* = 11.26%, *SD* = 22.64%) was higher compared to congruent target trials following repeated cross-court shots (*M* = 1.46%, *SD* = 20.89%), *t*(56) = 2.365, *p* = .022, d_{unb} =

0.44, 95% CI [0.07, 0.83]. For incongruent trials, prediction accuracy in target trials following repeated down-the-line shots (*M* = -15.94%, *SD* = 21.16%), differed stronger from baseline values compared to the other pattern (*M* = -1.46%, *SD* = 20.34%) as well, however, this difference had a negative algebraic sign this time, *t*(56) = 3.508, *p* = .001, d_{unb} = 0.69, 95% CI [0.28, 1.11].

None of the remaining main or interaction effects were statistically significant.

8.3.3.3 Response time

The 2 (Skill) x 3 (Length) x 2(Pattern) x 2 (Congruence) ANOVA revealed a significant *Pattern* x *Congruence* interaction, $F(1, 55) = 22.634$, $p < .001$, $\eta_p^2 = .292$. A *Length* x *Congruence* interaction just barely missed statistical significance, $F(1.893, 104.139) = 3.136$, $p = .05$, $\eta_p^2 = .054$.

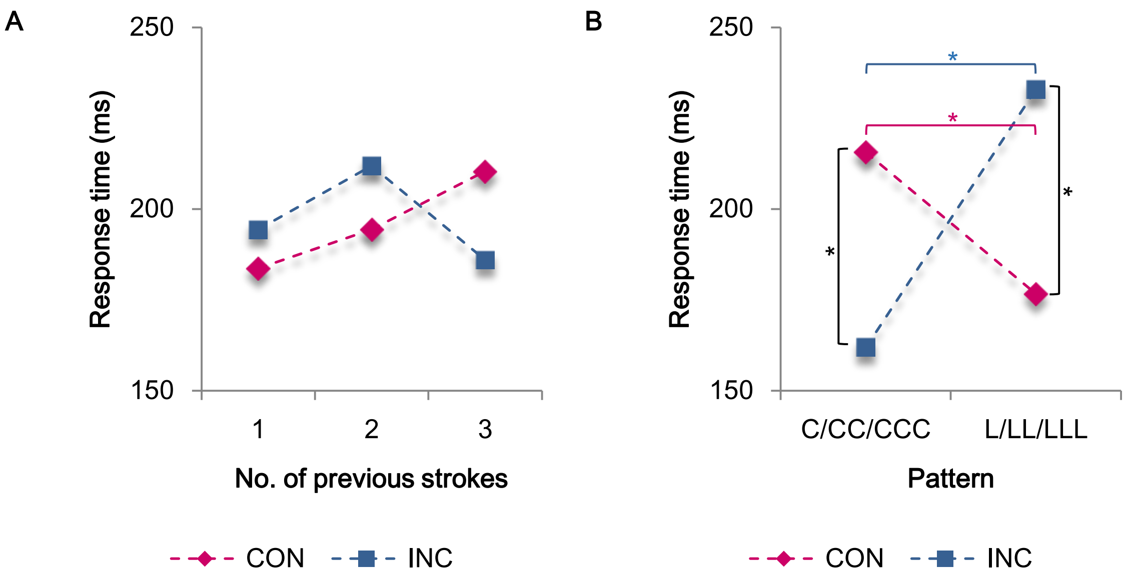


Fig. 42 **A.** Response time (ms) in congruent and incongruent target trials following one, two or three repeated shots to the same direction. **B.** Response time (ms) in congruent and incongruent target trials following the patterns C / CC / CCC or L / LL / LLL. Error bars represent 95%-confidence intervals, * ≙ p < .05.

Visual inspection of Fig. 42A and further analysis through pairwise comparisons showed that for target trials presented after sequences of one or two preceding shots to the same direction, response times were higher in incongruent target trials as opposed to congruent target trials. Conversely, for target trials presented after three preceding shots to the same direction, response times were higher in congruent target trials and lower in incongruent target trials. However, pairwise comparisons did not reveal any significant differences.

For sequences of repeated cross-court shots (across all lengths), response times were higher in congruent (M = 215.56 ms, SD = 279.68 ms) compared to incongruent (M = 161.86 ms, SD = 251.79 ms) target trials, $t(56) = 3.641$, $p = .001$, $d_{unb} = 0.20$, 95% CI [0.09, 0.32]. For sequences of repeated down-the-line shots (across all lengths), response times were higher in incongruent (M = 232.87 ms, SD = 273.82 ms) as opposed to congruent (M = 176.59 ms, SD = 213.45 ms) target trials, $t(56) = 3.593$, $p = .001$, d_{unb} = 0.23, 95% CI [0.10, 0.36] (see Fig. 42B). Looking at the congruent trials only, response times were higher in target trials following repeated cross-court shots (M = 215.56 ms, SD = 279.68 ms) than down-the-line shots (M = 176.59 ms, SD = 213.45 ms), $t(56) = 2.147$, $p = .036$, $d_{unb} = 0.16$, 95% CI [0.01, 0.30]. For incongruent trials, response times were higher in target trials following repeated down-the-line shots (M = 232.87 ms, SD = 273.82 ms) than cross-court shots (M = 161.86 ms, SD = 251.79 ms), $t(56) = 4.205$, $p < .001$, $d_{unb} = 0.27$, 95% CI [0.13, 0.40].

None of the remaining main or interaction effects were statistically significant.

8.3.4 Non-target trials

8.3.4.1 Prediction accuracy

For prediction accuracy in non-target trials, tennis players (M = 72.69%, SD = 6.02%) were superior to novices (M = 62.99%, SD = 5.79%), $t(55) = 6.202$, $p < .001$, d_{unb} = 1.62, 95% CI [1.04, 2.24]. Furthermore, both groups performed clearly above the level of chance; tennis players: $t(26) = 19.575$, $p < .001$, $d_{unb} = 3.66$, 95% CI [2.68, 4.85], novices: $t(29) = 12.295$, $p < .001$, $d_{unb} = 2.19$, 95% CI [1.56, 2.92].

8.3.4.2 Response time

No significant differences in response times between tennis players (M = 277.56 ms, SD = 223.68 ms) and novices (M = 195.90 ms, SD = 313.38 ms) were found, $t(55)$ = 1.121, $p = .267$, $d_{unb} = 0.29$, 95% CI [-0.23, 0.82]. Both groups responded significantly later than racket-ball-contact; tennis players: $t(26) = 6.448$, $p < .001$, $d_{unb} = 1.21$, 95% CI [0.73, 1.74], novices: $t(29) = 3.424$, $p = .02$, $d_{unb} = 0.61$, 95% CI [0.23, 1.01].

8.4 Discussion

When anticipating opponents' action intentions in time-constrained sport situations, athletes rely on both kinematic and contextual cues to guide their expectations. Amongst others, the outcome of previous events (e.g., Gray 2002) and particularly patterns in previous event outcomes (e.g., Loffing et al., 2015) seem to influence anticipatory behavior in subsequent events. Following Study 2, which demonstrated that a server's choices of serve direction and patterns in a sequence of choices have the potential to bias expectations towards a subsequent serve, Study 3 examined the patterns in an opponent's choices of shot directions within rallies in order to determine the potential influence on anticipatory behavior when awaiting subsequent shots. Specifically, my primary focus was grounded in whether visual anticipation of forehand baseline shots differs in trials which are congruent vs. incongruent with a pattern of preceding shot directions (Research question 1) and whether the length of a pattern moderates the role of this effect (Research question 2).

The differences between skilled tennis players and novices identified in prediction accuracy for both target and non-target trials indicates that the experiment allowed capturing factors of tennis-specific perceptual-cognitive expertise. Furthermore, the absence of skill-differences in response times for both type of trials, leads to the assumption that the higher prediction accuracy of tennis players was not at the expense of later responses.

8.4.1 Research question 1

With regards to the first aim of the study, patterns in previous shot directions were examined (all cross-court [CCC], all down-the-line [LLL] or CLC/LCL) to determine the potential for influence on anticipatory performance in a subsequent shot. Therefore, prediction accuracy and response times for congruent and incongruent target trials, presented as fourth shot in a rally, were analyzed. Based on the results of Study 2, as well as research findings within the existing literature (e.g., Gray, 2002a; Loffing et al., 2015), I suspected that participants would show varying anticipatory performance in target trials depending on which pattern of shot directions was presented. I assumed that participants would rather expect a chance of direction as opposed to yet another shot in the same direction. Correspondingly, for repeating patterns (CCC and LLL), I expected that prediction accuracy would be higher and response time would be lower in incongruent (C after LLL and L after CCC) as opposed to congruent (C after CCC and L after LLL) trials. For the alternating patterns (CLC/LCL), I assumed that prediction accuracy would be higher and response time would be lower in congruent (C after LCL and L after CLC) as opposed to incongruent (C after CLC and L after LCL) trials. However, due to the complexity of the development of a rally in tennis, assumptions were rather vague.

In fact, prediction accuracy differed when target trials were presented as first shot of a rally and hence, with no prior information as opposed to fourth shot in a rally. This indicates that the outcome of previous shots affects expectations towards a subsequent shot even in the presence of opponent's kinematics. This is in line with previous research findings which suggest an influence of prior information on anticipatory behavior, in particular event outcomes and event sequences (Gray, 2002; e.g., Loffing et al., 2015; Murphy et al., 2016).

Overall, participants seemed to exhibit improved prediction accuracies in target trials that were congruent with a preceding pattern in an opponent's choices of shot directions as opposed to incongruent trials, in which mean prediction accuracy was overall lower compared to baseline values (see Fig. 34B, p. 148). This finding is in line with earlier results of Loffing et al. (2015), who detected a likewise pattern-induced expectation bias in volleyball, as well as the results found in Study 2. However, the presence of several two-way interactions and a three-way-interaction call for a closer look at this aspect. The detected congruence effect seems to depend on the type of pattern present in the sequence of the opponent's choices of shot direction. Additionally, the skill level plays a decisive role here. Novices seem to improve their prediction accuracy in congruent target trials when they were shown as fourth shot in a rally as opposed to when no prior information is shown. This tendency was apparent irrespective of type of pattern, however, no statistical effects were found (see Fig. 35, p. 149). Nevertheless, in line with the findings from Study 2, but contrary to the a priori hypothesis established, this suggests that overall, they seem to expect the continuation of a pattern rather than a disruption. For skilled tennis players, Δ-prediction accuracies were overall higher (in both, positive and negative direction) when compared to novices, denoting a stronger effect of prior information about the course of the rally for skilled as opposed to unskilled participants. Furthermore, the type of pattern present in the previous shot directions of the opponent seems to play a crucial role for tennis players only (see Fig. 35, p. 149). While in target trials following the CCC pattern, positive values of Δ-prediction accuracy in incongruent, and concurrently negative values of Δ-prediction accuracy in congruent target trials, indicate that they expected a disruption of the pattern (i.e., a down-the-line shot) rather than a continuation. The opposite was the case for the alternating pattern CLC/LCL. The results confirm the hypothesis that participants more readily expect a change of direction as opposed to yet another shot in the same direction. For the pattern LLL, no differences in Δ-prediction accuracy between congruent and incongruent trials were found. However, generally participants performed worst in target trials following this pattern (see Fig. 34A, p. 148) indicating that it was most difficult to gain any useful information here. Regarding the course of rallies in real tennis matches this makes sense. Skilled tennis players know that repeated down-the-line shots occur quite infrequently, and therefore the presentation of this pattern may further facilitate confusion rather than benefit anticipation. The absence of a corresponding effect for novices underlines this assumption, as they lack such domain-specific knowledge.

Response times partially reinforce the findings pertaining to prediction accuracy. For target trials following the CCC pattern, response times were lower compared to the other patterns, in particular the alternating pattern. Additionally, response times were significantly shorter for incongruent as opposed to congruent target trials following the CCC pattern. This underscores the notion that participants expected a change of direction here, answering earlier and reaching higher prediction accuracies in incongruent target trials. For the other two patterns, no meaningful effects were detected. For the alternating pattern response times tended to be highest, militating in favor of previous research findings suggesting that alternating patterns require a greater number of occurrences when compared to repeating patterns, before a predictive model can be established (Huettel et al., 2002), which may facilitate faster response times and higher prediction accuracies.

8.4.2 Research question 2

With regard to the second study aim, I examined whether a preceding sequence of repeated shots to the same direction influences anticipatory behavior in a subsequent shot and if the congruence effect is moderated by the length of a preceding pattern. I assumed that expectations towards the outcome of a subsequent shot will not only vary depending on the pattern itself, but also on the length of this pattern and how many successive shots were previously played, respectively. For repeated cross-court shots I assumed that for short sequence lengths (e.g., one previous shot) participants would expect a congruent subsequent shot (i.e., a cross-court shot after one previous cross-court shot). However, with increasing sequence length, I suspected that the subjective probability of the participants for a shot to the other direction will increase, resulting in higher prediction accuracies and faster decision times, respectively, in incongruent target trials as opposed to congruent target trials. For repeated down-the-line shots the formulation of a distinct a priori hypothesis was difficult, as the occurrence of such a pattern is rather uncommon in real matches. It was assumed that skilled tennis players and novices would exhibit differences in behavior; however, a clear-cut a priori prediction as to which skill group would be more induced by patterns of previous outcomes was difficult to make.

First of all, across all lengths, prediction accuracy was higher in congruent as opposed to incongruent target trials. Compared to baseline values, prediction accuracy was higher in congruent and lower in incongruent target trials (see Fig. 39A, p. 156) indicating that overall, participants expected a continuation rather than a disruption of a certain pattern in players's choices of shot direction. Interestingly, a *Group* x *Congruence* interaction suggests that this congruence-effect was mainly evoked by the group of novices (see Fig. 40B, p. 157). Novices showed clear differences in prediction accuracy between congruent and incongruent target trials, suggesting that they expected an opponent to choose the same shot direction as in the preceding one, two or three shots instead of switching directions. This is in line with previous research findings in Baseball (Gray, 2002) and Volleyball (Loffing et. al, 2015) and goes with the results from Study 2. Tennis players showed no differences in prediction accuracy when target trials were presented as first shot in a rally compared to when they were presented as congruent target trial following one, two or three repeated shots to the same direction, and only a small decrease in prediction accuracy compared to when they were presented as incongruent target trials. Considering the results pertaining to the first research question, contrary effects present for the two different patterns (repeated cross-court shots vs. down-the-line shots) might have cancelled each other out here. However, no 3-way-interaction was found that could affirm this assumption. Nevertheless, a *Pattern* x *Congruence* interaction indicates that the difference in prediction accuracy between congruent and incongruent target trials was particularly evident for repeated down-the-line shots (see Fig. 41, p. 158). The occurrence of several two-way interactions makes it difficult to get a clear picture of the results. To facilitate the discussion, figure 43 illustrates Δ-prediction accuracy in congruent and incongruent target trials, following one, two or three repeated shots to the same direction, differentiated by pattern and separately for novices and tennis players.

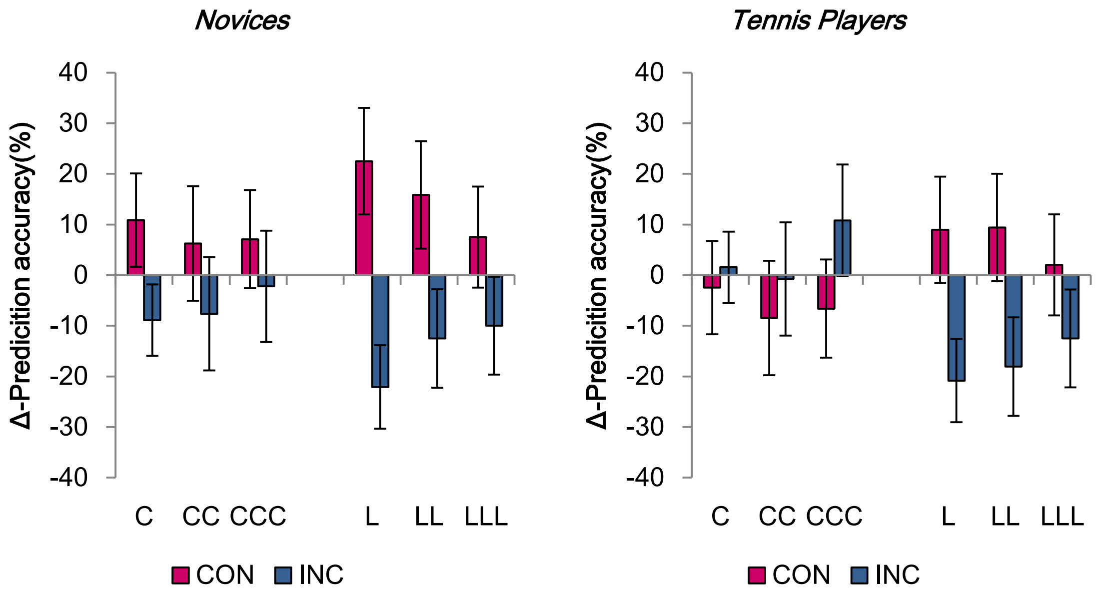


Fig. 43 Δ-Prediction accuracy (%) of novices and tennis players in congruent and incongruent target trials following one, two or three repeated shots to the same direction differentiated by pattern. Error bars represent 95%-confidence intervals, * ≙ $p < .05$.

Fig. 43 clarifies the results. Novices reached higher prediction accuracies in congruent target trials compared to baseline values, and lower prediction accuracies in incongruent target trials compared to baseline values. This implies that they expect an opponent to direct his shot to the same side as the preceding one, two or three shots rather than to switch directions, and accordingly, the continuation of a pattern in an event sequence. This underlines the results found by Gray (2002) on anticipating pitches in baseball as well as findings by Loffing et al. (2015) on awaiting attacks in volleyball. The effect turns out to be stronger for repeated, down-the-line shots as opposed to repeated, cross-court shots. A possible explanation is based on the varying difficulties associated with foretelling the outcome of forehand, down-the-line and forehand, cross-court shots in general (e.g., Buckolz et al., 1988). As it is easier to identify cross-court as opposed to down-the-line shots based on the kinematic cues inherent in the opponent's movement, observers may rely less on other (contextual) cues, such as the outcome of previous shots. Thus, the higher uncertainty associated with the kinematics of a down-the-line shot may encourage the reliance on non-movement related cues and therefore strengthen the role of previous event outcomes in the anticipation process.

For tennis players, overall prediction accuracy in target trials that were presented as second, third or fourth stroke in a rally did not diverge clearly from the corresponding baseline values. Apparently, the conclusion drawn based on the analysis of target trials presented as fourth stroke in a rally (Research question 1) needs to be revised. It seems like skilled tennis players were less influenced by the outcomes of preceding shots compared to their novice counterparts. A possible explanation is that experts are able to derive enough useful information from the kinematics of the opponent that allows them to neglect other possible sources of information such as previous event outcomes. On the other hand, movement kinematics do not provide enough information for the "untrained eye", forcing novices to rely on other cues, such as suspected patterns in opponent's choices of stroke direction.

Concerning the factor length, overall findings are in accordance with the hypothesized results. It was hypothesized that with increasing sequence length, the subjective probability of the participants for a shot to the other direction will increase. Across both groups and both types of patterns this was indeed suggested (see Fig. 38B, p. 157), with novices again providing a clearer image. While target trials presented after only one preceding shot displayed a strong difference in Δ-prediction accuracy between congruent and incongruent target trials, this difference decreased when target trials followed two previous shots to the same direction. For three repeated shots to the same direction, differences between congruent and incongruent target trials dissolved. By including response time data, this finding is further underlined. While response times were faster in congruent as opposed to incongruent trials following one or two preceding shots to the same direction, the opposite was the case when target trials followed three repeated shots to the same direction (see Fig. 42A, p. 159). Apparently participants first exhibit a positive recency (see chapter 3.1.1.4), which is reflected in the expectation that a certain event will continue to occur. However, with increasing sequence length, the positive recency may turn into a negative recency (see chapter 3.1.1.3), which manifests itself in the expectation of a disruption of a pattern, or in other words, that an opponent will change their choice of shot direction. The mechanisms behind this phenomenon can be of a different nature. First, following the theory behind sequence judgements, irrespective of the sport context (see chapter 3.1.2), participants may exhibit a *gambler's fallacy* (see chapter 3.1.1.3; Misirlisoy & Haggard, 2014). In other words, after several occurrences of the same event outcome (here: a specific shot direction) their subjective probability for the opposite phenomenon increases. Alternatively, participants may base their expectations on domain-specific knowledge about typical courses of rallies in tennis and game strategy which may lead them to expect the continuation or the disruption of a pattern in an opponent's choices of shot directions. As tennis players are in sole possession of such domain-specific knowledge, it can be assumed that the nature of the mechanisms lying behind the effects of previous event outcomes on anticipatory behavior in tennis may differ for novices and tennis players, though such processes are not identifiable in data from this type of research. Additional collection of verbal reports may shed more light on the mechanisms behind pattern-induced expectations. However, as sequence-driven judgements may take part on an unconscious level, there is no guarantee that verbal data will add to the findings.

8.4.3 Performance in non-target trials

The expert-novice differences found in the prediction accuracy in non-target trials are not surprising and are consistent with a multitude of research studies frequently showing an expert-advantage in anticipating opponent's action intentions, in particular for racket sports (Abernethy, 1990a, 1990b; Cañal-Bruland & Williams, 2010; Goulet et al., 1989; A.M. Williams et al., 2002). However, it strengthens the validity of the experimental design. Apparently, a profound domain-specific knowledge was essential for successful completion of the experimental task. No differences in response times were found between the two skill-groups, leading to the assumption that the higher prediction accuracy of tennis players was not at the expense of later responses.

8.4.4 Study limitations and research perspectives

While findings of Study 3 are encouraging with regard to better understanding the role of contextual cues (here: outcome of previous events) for anticipation, some study limitations have to be acknowledged.

First, the study design did not allow for an exact identification of the perceptual-cognitive mechanisms underlying the detected effects of patterns in an opponent's choices of stroke directions on prediction performance. It was assumed that an increased subjective probability for either a continuation or a disruption of a certain pattern may have led participants to partially neglect the opponent's movement kinematics. Furthermore, it remains unclear how these subjective probabilities even build up. It was suggested that the mechanisms behind the development of certain subjective probabilities for the outcome of an event may vary based on the level of domain-specific knowledge. Surely, further evidence is needed to verify these assumptions and to shed more light on the perceptual-cognitive mechanisms behind the detected effects. In this regard, next steps could be (1) to additionally collect visual search data and examine whether the participants' visual information pick-up strategies depend on the outcome of patterns in opponents' previous choices of shot direction (e.g., McRobert et al., 2011), (2) to collect verbal report data (Schlaeppi-Lienhard & Hossner, 2015) to identify whether patterns in opponents' choices of shot directions are used consciously or unconsciously when making predictions about a future event and if the way of thinking here depends on the level of domain-specific knowledge.

Second, only three different types of patterns were analyzed (all cross-court shots, all down-the-line shots, alternating pattern), while other patterns exist that may occur even more frequently in real tennis games, e.g., two forehand cross-court shots followed by one down-the-line shot. However, for the second research question, the 4-step factor length of a sequence was integrated and a cutback of the number of pattern types was essential to (1) allow for the comparison of three different lengths by producing a similar pattern in one, two or three previous shots, and (2) to limit the number of overall experimental trials for the participants.

Third, the testing environment was a laboratory setting in which participants were asked to watch videos of tennis shots on a laptop and press a button corresponding to the likely direction of the shot. Against the background of perception-action coupling (Goodale & Milner, 1992; Van der Kamp et al., 2008), this test design may limit the transferability of the findings to real world tasks. Precisely, two different scenarios are imaginable regarding the role of previous stroke outcomes (or more general: contextual information) in real world compared to laboratory settings: It seems that the level of anticipatory skill found when performing perceptual judgements underestimates that of which is found when performing motor actions (cf. D. L. Mann et al., 2014, p. 7). Therefore, it might be reasonable to expect that patterns in previous shot directions could have a stronger effect on anticipatory behavior when asked to produce a motor response. Additionally a whole-body movement could lead to a higher level of awareness and thus, susceptibility to patterns in opponents' choices of shot direction. Alternatively, "it is possible that the strong perception-action coupling inherent in a motor response may be more impervious to 'interruption' by situational information than a perceptual response" (D. L. Mann et al., 2014, p. 7). Therefore, previous shot directions may play a less important role in a more realistic test environment. I strongly agree with Mann et al. (2014) that further research is needed to examine whether contextual information (like previous event outcomes) influences perceptual and motor anticipatory decisions differently. However, this aspect should not depreciate the results of this study, as researchers have repeatedly highlighted the veracity and generalizability of findings regarding perceptual expertise in existing laboratory based studies (e.g., Farrow et al., 2005).

8.5 Conclusion

Collectively, the results found in Study 3 reveals that the visual anticipation of shots within rallies, as demonstrated by skilled tennis players' and novices', is affected by expectations based on patterns in the opponent's previous shot directions. However, these expectations seem to differ between the two skill groups. Novices expected an opponent to direct his shot to the same side as the preceding one, two or three shots rather than to switch directions and accordingly, expected the continuation of a pattern in an event sequence (for similar findings see e.g., Gray, 2002; Loffing et al., 2015). Results were not that clear for tennis players. They showed different expectations depending on the type of pattern apparent in opponents' previous shot directions, indicating that their pattern-induced expectations cannot be sufficiently explained by theories of sequence judgments. I suggested that they rather incorporate domain-specific knowledge about characteristic sequences of opponents' choices of shot directions. Overall, tennis players expected a disruption rather than a continuation of a certain pattern in opponents' shot directions, particularly for repeated cross-court shots or alternating shot directions.

Findings of Study 3 support the assumption that athletes rely on both kinematic and contextual cues when visually anticipating opponent's action intentions (Buckolz et al., 1988; Loffing & Hagemann, 2014a; Loffing et al., 2015). Previous event outcomes, in our case shot directions within tennis rallies, and moreover patterns in these outcomes, affect expectations even in the concurrent presence of an opponent's kinematics (Gray, 2002; Loffing et al., 2015). Such expectations, however, do not necessarily benefit anticipation but may mislead an athlete. Predominantly, novices showed decreased prediction performance when a sequence of shot directions did not continue in the target trials as opposed to when it did, irrespective of identical kinematic cues. Skilled tennis players also exhibited a pattern-induced expectation bias. Although the influence seems weaker compared to novices, both tennis players and beginners might benefit from being made aware of the potential detrimental effects of setting probabilities about future action outcomes based on previous shot directions. That way they might be less likely to overlook anticipation-relevant cues from the opponents' actions. On the other hand, athletes may take advantage of an opponent's susceptibility to patterns in their own choices of shot directions. That is, they may try to manipulate an opponent's subjective probability as to the next shot direction by initially producing a certain pattern in their shots, e.g., cross-court - down-the-line - cross-court, and to then interrupt this sequence, e.g., with another cross-court shot. Although to date this has not been scientifically examined, this is indeed a common tactic known amongst tennis players: to purposely aim the ball against the run direction of an opponent, which means, in most cases, in the same direction as the previous shot.

9 GENERAL DISCUSSION

The purpose of the general discussion is to critically reflect upon the gained findings against the theoretical background and the derived research questions of the dissertation project as a whole. It should serve less to explain the results of the individual research studies (for this, please see the discussions of Study 1 – 3).

The purpose of this dissertation was to investigate the effect of previous event outcomes on visual anticipation of action outcomes in time-constrained sport situations and thus, to contribute to a deeper understanding of the significance of non-kinematic, contextual cues within the anticipation process.

When anticipating opponent's action intentions in time-constrained sport situations (e.g., when awaiting a serve in tennis or a penalty kick in soccer), athletes may rely on both kinematic cues from their opponent's movements and contextual cues (Abernethy et al., 2001; Buckolz et al., 1988). A large body of research delivers evidence that skilled athletes possess superior anticipation skills compared to less skilled players or novices (e.g., Abernethy et al., 2001; Rowe & McKenna, 2001; Singer, Cauraugh, Chen, & Steinberg, 1996; for a review, see A.M. Williams, Ford, Eccles, & Ward, 2011). The majority of research studies focused on investigating the impact of kinematic cues (i.e., the opponent's motion sequence) suggesting that the skill-effect can be partially explained by differences in the visual-information pick-up and/or the superior ability of skilled athletes to interpret such cues (e.g., Abernethy & Russell, 1987b; Huys et al., 2008; A.M. Williams, Huys, Cañal-Bruland, & Hagemann, 2009). While the examination of the influence of non-movement-related information on expectations towards an opponent's action intentions has been neglected for quite a while, there is now an increasing interest in investigating the role of contextual cues in the anticipation process. A recent call has been made to encourage researchers to work towards a better understanding of this issue (see Cañal-Bruland & Mann, 2015). Aside from general event probabilities (Cañal-Bruland et al., 2014; Cañal-Bruland & Schmidt, 2009; Mueller et al., 2006), knowledge of a player's action preferences (e.g., Barton et al., 2013; D. L. Mann et al., 2014; Navia et al., 2013), game score (Farrow & Reid, 2012; Gray, 2002; Paull & Glencross, 1997), level of tactical initiative (Crognier & Féry, 2005) and an opponent's on-court position (Loffing & Hagemann, 2014a), the history of previous event outcomes was assumed to be integrated into the anticipation process and to bias expectations towards an opponent's action intentions (Gray, 2002; Loffing et al., 2015; Misirlisoy & Haggard, 2014). Both beneficial and detrimental effects of the availability of the above-mentioned contextual cues were found, for example, when misleadingly expecting that an opponent continues to behave in accordance to his before shown preferences (e.g., D. L. Mann et al., 2014) or that a pattern of event outcomes would continue in a subsequent manner (e.g., Gray, 2002; Loffing et al., 2015). However, findings on the role of contextual cues in general, and specifically on the influence of previous event outcomes on visual anticipation, are to date rather rare and involve some limitations that possibly restrict the generalization of the results. Gray (2002) acknowledges that participants in his study on baseball batting faced simulated pitches where only ball flight, but not a pitcher's kinematics, was available. However, as the anticipation process is characterized by the integration of both information from the opponent's kinematics and prior knowledge (i.e., contextual information), Gray's study design may have artificially favored the reliance on previous pitch outcomes. Furthermore, the effect of previous event outcomes reported by Gray (2002) was specific to trials that were preceded by identical outcome patterns. However, based on related research in the field of experimental psychology (e.g., de Lussanet et al., 2001, 2002; Huettel et al., 2002) which has suggested that people are highly sensitive to all kinds of sequential patterns in their environment, it seems reasonable to expect that pattern-induced expectations also occur, for example in sequences of events with alternating outcomes. Loffing et al. (2015) successfully addressed these two issues in their study on visual anticipation of action outcomes in volleyball. Nevertheless, as their study is to date the only one of this kind, further research was warranted in order to (1) confirm the existing findings on the effect of previous event outcomes on anticipatory behavior and facilitate their generalization, (2) to reveal possible skill-related differences regarding the susceptibility to prior event outcomes or weighting of contextual information in general and (3) to explore further determinants which may moderate a detected effect, such as the length of event sequences or individual characteristics of an athlete. Moreover, further research findings may support the identification of the perceptual-cognitive mechanisms underlying sequence-driven predictions.

A tripartite research program was developed to address these issues. In the first study, a notational analysis of 15 professional tennis matches between two right-handed players (22 different players were involved), played on hard courts at international Association of Tennis Professionals (ATP) and Grand Slam tournaments in 2014, was carried out. It focused on the players serve behavior and in particular, the sequences of the players' choices of serve directions. It was explored whether choices of serve directions are independent of one another and whether specific patterns in sequences of serve directions occur more or less often than others, suggesting that servers follow certain strategies, e.g. switching serve sides on purpose after a particular number of identical serves or alternating serve directions. Additionally, it was examined whether preceding sequences of serves and pattern in these sequences combined with the choice of the current serve direction are associated with varying efficiency involved with the serve and the ultimate result of the rally. Findings confirmed that tennis players seem to be able to generate sequences of serve directions that correspond to a random sequence (Chiappori et al., 2002; Palacios-Huerta, 2003; Walker & Wooders, 2001). Overall, high variations in the data indicated that serve behavior or choices of serve direction strongly depended on the individual athlete and the match situation. In general, servers seemed to be more successful when they choose the opposite serve direction of the preceding serve as opposed to the same direction. The percentage of points won by the server after an incongruent serve tends to increase with increasing sequence length of identical serve directions. Study 1 delivered first indications that return players may set subjective probabilities as to the outcome of the next serve based on previous serve directions and that servers may gain an advantage out of this by systematically manipulating these probabilities and subsequently exhibiting an opposite behavior. However, the real match data did not allow conclusions to be drawn about whether previous serve directions directly affected the expectations of a return player towards the outcome of a subsequent serve. This question was addressed in Study 2, which examined whether patterns in previous serve-sequences of different lengths affect tennis serve outcome anticipation. To this end, 30 tennis players and 30 novices watched videos of tennis serves stopping 40 ms after (non-target trials) or at (target trials) racket-ball-contact and were asked to predict serve direction (left vs. right) as accurately and quickly as possible via key press. Similar to recent works (Loffing et al., 2015), serves were presented in blocks of six, each containing one target trial where identical serves were presented to control kinematics. In half of the blocks, the third trial served as target trial, and the outcomes of the preceding two serves were manipulated under four conditions: two serves to the right (R) or left (L), RL or LR. In the other half, the fifth trial served as target trial; correspondingly, the preceding four serves were varied: RRRR, LLLL, RLRL, and LRLR. Results revealed that participants tended to expect a serve pattern to continue (e.g., serve to R after RR or RRRR) rather than to break (e.g., serve to L after R or RRRR), which was reflected in a higher prediction accuracy in congruent (e.g., R after RR/RRR or RL/RLRL) as opposed to incongruent target trials (e.g., L after RR/RRR or RL/RLRL). The effect was larger in trials preceded by four as opposed to two serves, indicating that sequence-length may be a moderating factor.

While Study 2 focused on the examination of the effect of patterns in serve sequences, Study 3 examined whether patterns in an opponent’s shot directions within rallies affect anticipatory performance and, in a second step, how different sequence lengths may moderate such an effect. To this end, 27 skilled tennis players and 30 novices were asked to anticipate shot directions in tennis rallies in a video-based task. Each shot of the opponent was stopped at racket-ball-contact and participants were asked to predict shot direction (cross-court/right vs. down-the-line/left) as accurately and quickly as possible via key press. Similar to Study 2, each rally contained one target trial where identical shots were presented in order to control for the player’s kinematics. This was realized with the help of video-editing software. To test the first study aim, target trials were presented as fourth shot in a rally and patterns in previous shot outcomes were manipulated under three conditions: three strokes cross-court (C) or down-the line (L) or CLC/LCL. To test the second study aim, target trials were also presented as third, second or first shot in a rally. For patterns with identical outcomes (i.e., CCC and LLL) it was examined whether the length of the sequence is a moderating factor influencing the effect of previous shot outcomes on anticipatory behavior in a subsequent shot. Results revealed that prior information, in this case the outcome of previous shots in a rally, influenced anticipation of shot directions, even in the presence of an opponent’s kinematics. This was reflected in significantly varying prediction accuracies when target trials were presented without prior information compared to when they were presented as second, third or fourth stroke in a rally. However, the skill level of participants played a decisive role here. Overall, novices showed improved prediction accuracies in target trials that were congruent with a preceding pattern of shot directions, irrespective of type of pattern and pattern length, underlining the results found in Study 2. Additionally, a slow decrease of Δ-prediction accuracy with increasing pattern length speaks in favor of a negative recency. However, it is difficult to assess what would have happened with continuing sequence lengths, as no sequences with more than three preceding strokes were integrated in the experiment. Experts were also influenced by outcomes of preceding shots. However, on the one hand, the effect of previous shot directions was smaller compared to novices, indicating that skilled players are able to derive enough useful information from the kinematics of the opponent which allows them to neglect other possible sources of information such as previous event outcomes. On the other hand, the effect depended on the type of pattern, indicating that they incorporated domain-specific knowledge about the course of rallies to solve the anticipation task.

9.1 Emergent themes and implications of findings

The key finding of the present research is that the outcome of previous events and patterns in previous event sequences influence anticipation towards a subsequent event in time-constrained sport situations even in the presence of kinematic cues. Findings of the tripartite research program confirm that event history depicts a relevant contextual cue when making predictions about an opponent's action intentions. Therefore, Study 2 and Study 3 can be successfully added to Tab. 2 (p. 48), as they contribute to the existing body of research studies examining the role of contextual cues for anticipatory performance in sports. The present research confirms and concurrently broadens the findings on event history in dynamic sport tasks delivered by Gray (2002) and Loffing et al. (2015).

In the theoretical part of this dissertation a model was developed that illustrates the temporal availability and interaction of different information sources in the anticipation process (see p. 51) based on the existing body of literature. Following the present research findings, their compatibility with the developed model asks for a little modification. In the proposed model, event history, or in other words the outcome of previous events, was classified as an action-independent contextual cue. Moreover, it was highlighted that action-independent cues (e.g., preferences of an opponent, game score or previous action outcomes) seem to be used by and benefit both, skilled and less skilled athletes (Barton et al., 2013; Loffing et al., 2015; Paull & Glencross, 1997), while action-dependent contextual cues (e.g., players' on-court position) seem to be a salient cue especially for experienced players (Abernethy et al., 2001; Loffing & Hagemann, 2014a). It was argued that this might be due to the fact that knowledge of task-specific constraints or the like is necessary to identify varying probabilities associated with action-dependent cues (e.g., an opponent's on-court position in tennis). The findings on the role of event history in the anticipation process delivered by Gray (2002) and Loffing et al. (2015), as well as the present findings of Study 2 speak in favor of the classification of event history as action-independent cue, which is underlined by an absence of a skill effect in the findings. However, results of Study 3 suggest that previous event outcomes cannot be categorized as action-independent or skill-independent contextual cue per se. Here, differences in pattern-induced expectations towards the outcome of shots within rallies can clearly be attributed to domain-specific knowledge of the skilled group. Apparently, whether event history can be regarded an action-/skill-independent or action-/skill-dependent contextual cue depends on the experimental task or rather the framework of the corresponding sport situation. Serves, as examined in Study 2, can be seen as isolated, notionally independent events. The direction of a serve, and correspondingly the speed of a baseball pitch (Gray, 2002) or the type of volleyball attack (Loffing et al., 2015), is determined by only one party, which is the server, the pitcher or the attacking team. After one decision was made (e.g., to serve to the right side, to throw a fast ball or to execute a smash), in the next equivalent situation, another decision can be made notionally independent of the other party's behavior. The resulting sequence of event outcomes may not even reflect any characteristic of the sport domain but the individual preferences of one party to vary their own behavior in order to be as inscrutable as possible for an opposing party. Therefore, domain-specific knowledge is of no benefit here - a situation comparable to playing 'rock, paper, scissors'. However, sequences in tennis rallies are the result of an interaction between two players and therefore a direct expression of the characteristics of the game. Here, domain-specific knowledge would clearly allow for better predictions as to the progression of a rally. Moreover, the implication of a certain sequence of shot directions by a player which is currently in control of the rally may limit the spectrum of possible actions of his counterpart. In this case, event history (here: the outcome of previous shots within a rally) can be regarded as an action- and skill-dependent contextual cue. Therefore, event history, or in other words previous event outcomes, cannot be simply classified into one of the categories as proposed in the established model, but the nature of the task must be considered. Future research in related sport domains (e.g., badminton) could help to underline the conclusions drawn based on the present research.

The above section also highlights that the introduced theories of sequence judgements (particularly the markov model, see chapter 3.1.2) may only be partly transferred to sequence judgements within sport situations such as anticipating the direction of an opponent's serves (Study 2). Sport situations are highly complex and not only the outcome of previous events but various other factors such as the preferences of an opponent, the on-court position or postural cues apparently determine the expectation an actor has towards an opponent's action intentions. Therefore, a mental model explaining how human cognitive systems comprehend and reason through sequences can only be a fractional amount of a bigger model incorporating all perceptual-cognitive mechanisms that interact during the anticipation process in time-constrained sport situations. To gain more insight on this aspect, future research should try to examine the role of various contextual cues in a combined manner and at the same time, use a test design that includes multidimensional measurements (see chapter 9.4: Suggestions for future research).

A further emergent aspect of the present research is that the outcome of previous events has only be considered as the opponent's choice of serve and stroke direction respectively. This unidimensional point of view was necessary to develop a coherent test design that allows broadening the findings delivered by Gray (2002) and Loffing et al. (2015), that were rather exclusive until then. However, if we think of competitive sport situations, success and failure are what interests all participants the most. Therefore, regarding sequences of event outcomes, not only the outcome of the event per se, e.g., whether a server chose to serve to the left or the right side, but the effect the choice ultimately had, e.g., whether the return player had trouble returning the serve, may bias the expectations towards the server's subsequent choice of serve direction. The manipulation not only of the outcome of a certain events but also of associated success and failure in future research studies could help to broaden the understanding of the effect of event history on anticipatory behavior.

Regarding the practical implications of the results it should be remembered that the "identification of patterns within event sequences is automatic and obligatory" (Huettel et al., 2002, p. 485). Consequently, the regulation of the pick-up and usage of contextual information pertaining to the outcome of previous events within the anticipation process is only possible to a limited degree. Therefore, making athletes aware of their (unconscious) susceptibility to previous event outcomes should not have any negative effects. Rather, being aware of the potential detrimental effects of setting probabilities about a future action based on previous event outcomes may benefit athletes such that they might be less likely to overlook anticipation-relevant cues progressively available from their opponent's unfolding action (cf. Loffing et al., 2015, p. 9). If we think, for example, of the situation of a return player facing a serve, based on the found results in Study 1 and 2 it would be most beneficial to instruct the return player to basically ignore the server's previous choices of serve directions and focus solely on the unfolding of the server's action. However, research examining the role of an opponent's action preferences indicates that setting probabilities about an upcoming action based on before shown action preferences of an opponent can also be beneficial (e.g., D. L. Mann et al., 2014; Navia et al., 2013). Apparently the clue is to advantageously complement kinematic information by contextual information preceding the stroke. Besides the advice to "read the play" that must be added to the most traditional instruction of coaches to "keep your eye on the ball" (cf. Crognier & Féry, 2005), it will still be most beneficial to develop play strategies that enable fast reactions to all court areas (e.g., a split step or the positioning on the angle bisector) as well as to work on an advanced technique, a prudent tactical behavior and physical and mental fitness in general. The domain-specific knowledge that may promote the successful usage of contextual cues within the anticipation process is most likely a by-product of expertise-development.

> “I always thought Martina Hingis was a great anticipator of where the ball goes. I don’t think it’s enough today. I think you have to be very athletic and explosive. I think that’s what the top guys are doing at the top of the rankings […]. I think we all read the plays pretty good. Others read some players better than others. Some read certain serves better and some don’t. But I still think you need to be quick […]” (Federer, 2011).

9.2 Strengths of present research

A clear strength of this research is the contribution it makes to the existing body of knowledge. Although anticipation in time-constrained sport situations has received a large amount of attention over the past decades, the vast majority of according research has focused on the role of kinematic information in this context, with only little consideration of the role of non-movement related, contextual information. The theoretical part of this dissertation delivers a currently unique review of literature pertaining to the role of contextual cues in the anticipation process (Chapter 2.4.2) and the model developed on this basis poses a fruitful starting point for further research. The empirical studies, which build up on each other, contribute to our understanding of the influence of previous event outcomes (as a relevant contextual cue) on anticipatory behavior in time-constrained sport situations. In doing so, the real match data gained in Study 1, on the one hand, served as a basis for both experimental studies (in particular Study 2), which allowed the derivation of first assumptions regarding the role of event sequences and on the other hand, may additionally facilitate interpretation of the results found in the subsequent studies. Until now, not even a handful of research studies has directly addressed the effect of previous event outcomes on anticipatory behavior (for expectations see Gray, 2002; Loffing et al., 2015), although a large number of research indicates that event history is a non-negligible factor in decision making and particular in the sports context (see chapter 3). Furthermore, the present research incorporated the three determinants – the time pressure, the task and the athlete – assumed to determine the relevance of, and reliance on different sources of information in a dynamic sport situation. By limiting the amount of visual information available to the participants, using two different types of tasks within the same sport and including two skill groups, the present research allowed the gain of several new insights which sharpen our understanding regarding the significance of these determinants in the anticipation process.

Overall, the systematic tripartite research program makes a significant contribution to the existing body of knowledge and, at the same time, provides a starting point for a multitude of new research questions.

9.3 Limitations of present research

Throughout the research work, a number of limitations were identified and therefore must be addressed, particularly to draw attention to factors that should be considered in future research. The limitations acknowledged in Study 2 (see chapter 7.4.4) were addressed in Study 3. However, three serious limitations which exist across the present research as a whole, should be highlighted.

First, in Study 2 and 3, perceptual judgment tasks were used to measure anticipation performance, which required participants to respond via a button-press in a laboratory setting. However, in the real sporting context, the decision making of an actor is a lot more complex, requiring the successful coupling of perception and action in order to not only anticipate an opponent's action intention and the direction of a ball for example, but at the same time to decide where to return the ball and execute the adequate motor skill. Against the background of perception-action coupling (Goodale & Milner, 1992; Van der Kamp et al., 2008), this test design may limit the transferability of the findings to real world tasks. Precisely, the role of previous event outcomes or contextual information in general may differ depending on whether it is examined in a laboratory-setting or in a real world task. As discussed within the analysis of the results from Study 3, two different scenarios are imaginable: First, the level of anticipatory skill found when performing perceptual judgements may underestimate that found when performing motor actions (cf. D. L. Mann et al., 2014, p. 7). Therefore, it might be reasonable to expect that patterns in previous shot directions could have a stronger effect on anticipatory behavior when asked to produce a motor response. Additionally a whole-body movement could lead to a higher level of awareness and thus, susceptibility to patterns in opponents' choices of shot direction. Alternatively, "it is possible that the strong perception-action coupling inherent in a motor response may be more impervious to 'interruption' by situational information than a perceptual response" (D. L. Mann et al., 2014, p. 7). Therefore, previous shot directions may play a less important role in a more realistic test environment. Further research is needed to ascertain which of the two scenarios is more likely to reflect the reality (see following section).

Second, the study designs chosen in Study 2 and 3 do not allow for a concrete identification of the perceptual-cognitive mechanisms underlying the detected effects of previous event outcomes on anticipatory performance. Only assumptions can be drawn based on the differences in anticipatory performance measured through prediction accuracy and response time. It was assumed that an increased subjective probability for either a continuation or a disruption of a certain pattern may have led participants to partially neglect the opponent's movement kinematics and that the mechanisms behind the development of certain subjective probabilities for the outcome of a certain event may vary based on the level of domain-specific knowledge. A more multidimensional data collection including visual search data (e.g., McRobert et al., 2011) and verbal report data (e.g., Schlaeppi-Lienhard & Hossner, 2015) may help to shed more light on the perceptual-cognitive mechanisms behind the detected effects. This could help to answer questions that remained open throughout the present research, e.g., whether patterns in opponent's choices of shot directions are used consciously or unconsciously when making predictions about a future event and if the mechanisms behind pattern-induced expectations depend on the level of domain-specific knowledge.

Third, findings of the present research are not simply generalizable. They are first of all limited to time-constrained sport situations and secondly, it needs to be verified whether they can be transferred to other sports besides tennis. It can be assumed that findings comparable to that found for tennis serves (Study 2) may be found for soccer or handball penalties, as they depict a similar isolated 1-on-1 situation. Further, the effect of an opponent's previous choices in shot directions on expectation towards a subsequent shot within a rally (Study 3) may be replicated in related sport domains, such as badminton or table-tennis. However, further research including different task demands is needed. Overall, findings of the present research relate largely to the context in which it was examined.

9.4 Suggestions for future research

The findings of the current research program provide a basis for further investigations into the examination of contextual cues in general (and event history in particular) and their significance in the anticipation process in sports. Several possible starting points for future investigations have been highlighted throughout the dissertation and should now be shortly summarized.

First of all, the limitations that had to be acknowledged with regard to the present research studies favor the development of advanced test-designs for future research. Amongst others, more realistic testing environments should be chosen in order to ascertain whether the level of anticipatory skill found when performing perceptual judgements may underestimate or overestimate that found when performing motor actions. Additionally, the inclusion of a multidimensional test battery including, for example, verbal data collection or eye movement registration, may help to shed more light on the perceptual-cognitive mechanisms underlying the detected effects of contextual information in general and in particular, previous event outcomes on anticipatory performance in sport tasks. In general, the transition from quantitative research studies to a more qualitative approach with in-situ data collection (e.g., Schlaeppi-Lienhard & Hossner, 2015; Schlaeppi, Urfer, & Kredel, 2016) may have the potential to deliver fruitful new insights into the anticipation process and reveal potential anticipation-relevant cues. The implementation of an equivalent study in tennis is absolutely plausible. Furthermore, to enhance the generalizability of the findings it is important to assure the findings in other sport domains, such as badminton for example. As findings of research studies examining anticipation in sports relate largely to the context in which they were examined, the development of a model that precisely reflects the anticipation process in time-constrained sport situations and covers up all the individual game characteristics calls for an integration of research findings from a variety of sport domains. At the same time, the detection of differences and similarities in information usage across different sport tasks can shed more light on the significance of the task as a suspected determinant of the integration and weighting of different information sources within the anticipation process (see chapter 2.4.3).

In past research, relatively little attention has been paid to studying individual differences in experienced athletes anticipatory behavior and perceptual-cognitive skill respectively. Rather, expert-novice study designs were widely used to form general propositions about what distinguishes skilled and successful athletes from less-skilled aspirants. However, first research indicates that individual characteristic of (expert) athletes should not be neglected as they may play a significant role in the anticipation process (see chapter 2.4.3.1; Dicks et al., 2010). Based on this, Study 2 integrated two additional inventories to cover up individual differences pertaining to decision making in general. The lack of significant findings led to the assumption that the two inventories used were not adequate in revealing specific individual factors determining anticipatory behavior in sport situations rather than to object to the general assumption that individual characteristics may play a significant role. Future research should (1) think of other possible ways of measuring individual decision making characteristics and (2) generally integrate data collection regarding individual characteristics (e.g., action capabilities; Dicks et al., 2010) that may influence the anticipation and decision making process, respectively.

In the present research as well as in a multitude of research studies examining anticipatory skills in time-constrained sport situations, these skills were mostly investigated in a controlled environment. Further factors that typically characterize competitive sport situations (e.g., the pressure that is put on an athlete) were isolated. However, in order to draw meaningful conclusions which reflect reality to the best possible extent, it is desirable that future research tries to create test situations that incorporate such aspects that are specific to sport competitions. For example, an interesting question could be whether the information pick-up when anticipating an opponent's action intentions varies with different levels of mental or physical pressure that is put on an athlete.

10 Résumé

This dissertation examined the effect of event history on anticipatory behavior in tennis. The starting point of this work is that athletes rely on both kinematic cues from their opponent's movements and contextual cues when anticipating opponent's action intentions in time-constrained sport situations (e.g., when awaiting a serve in tennis; Abernethy et al., 2001; Buckolz et al., 1988). Based on the assumption that the outcome of previous events depicts a relevant contextual cue which influences anticipation towards a subsequent event in time-constrained sport situations even in the presence of kinematic information, a tripartite research program was developed. The main goal of this research was to verify and extend existing research findings (e.g., Loffing et al., 2015) and thus, to contribute to a deeper understanding of the significance of non-kinematic, contextual cues within the anticipation process.

In the first study, an extensive analysis of match data from professional tennis tournaments confirmed that tennis players seem to be able to generate sequences of serve directions that correspond to a random sequence (Chiappori et al., 2002; Palacios-Huerta, 2003; Walker & Wooders, 2001). High variations in the serve data indicated that serve behavior and choices of serve directions, respectively, strongly depended on the individual athlete and the match situation. Data suggests that servers are more successful when they choose to serve in the opposite direction of the preceding serve as opposed to the same direction and that this benefit increases with an increasing number of preceding serves aimed at the identical direction. Overall, Study 1 did not deliver any novel findings; however, it provided indications that return players may set subjective probabilities as to the outcome of the next serve based on previous serve directions of their opponent.

Study 2 experimentally examined whether patterns in an opponent's choices of previous serve directions affect expectations towards a subsequent serve. In a video-based experiment skilled players and novices were presented with tennis serves stopping 40 ms after (non-target trials) or at (target trials) racket-ball-contact, after which they were asked to predict serve direction (left vs. right). Serves were presented in blocks of

six, each containing one target trial (either as third or fifth serve) where identical serves were presented to control kinematics. In half of the blocks, the third trial served as target trial, and the outcomes of the preceding two serves were manipulated under four conditions: two serves to the right (R) or left (L), RL or LR. In the other half, the fifth trial served as target trial; correspondingly, the preceding four serves were varied: RRRR, LLLL, RLRL, LRLR. Both groups were less accurate in target trials that were incongruent vs. congruent with preceding patterns and the effect was larger in trials preceded by four serves as opposed to two. No effect was found for response time. Collectively, findings indicated that participants tended to expect a serve pattern to continue while possibly attaching less importance to kinematic cues.

A similar laboratory-based test design was developed for Study 3, which examined whether patterns in an opponent's shot directions within rallies affect anticipatory performance and, in a second step, how different sequence lengths may moderate such an effect. Here, participants were presented rallies and were asked to anticipate shot directions within these (cross-court vs. down-the-line). With the help of video-editing software, rallies were artificially created so they contained one target trial where identical shots were presented in order to control for the player's kinematics. Target trials were presented as fourth shot in a rally and patterns in previous shot outcomes were manipulated under three conditions which included: three strokes cross-court (C) or down-the line (L) or CLC/LCL. For patterns with identical outcomes (i.e. CCC and LLL), target trials were also presented as third, second or first shot in a rally, to test whether the length of the sequence is a moderating factor influencing the effect of previous shot outcomes on anticipatory behavior in a subsequent shot. Similar to Study 2, results revealed that outcomes of previous shots in a rally influence anticipation of shot directions, even in the presence of an opponent's kinematics. However, as opposed to Study 2, Study 3 revealed skill-differences. Novice athletes seemed to be more prone to patterns in previous shot directions compared to skilled players, indicating that skilled players are able to derive more useful information from the kinematics of the opponent and incorporate further domain-specific knowledge.

In summary, the present research demonstrates that visual anticipation of action outcomes in time-constrained sport situations is affected by expectations based on the

outcome of previous events and patterns in previous event sequences, even in the presence of kinematic information. Incorporating outcomes of previous events as a source of information can therefore benefit successful anticipation; however, overreliance on patterns in an opponent's previous actions may also be detrimental to anticipation in situations where an action's outcome does not correspond to a previous observed pattern. Overall, findings of the present research confirm that event history depicts a relevant contextual cue when making predictions about an opponent's action intentions. Future research should develop advanced (multidimensional) test designs that may help to shed more light on the perceptual-cognitive mechanisms underlying the usage, interaction and weighting of various contextual information sources and kinematic information in the anticipation process.

REFERENCES

Abernethy, B. (1990a). Anticipation in squash: Differences in advance cue utilization between expert and novice players. *Journal of Sports Sciences, 8*, 17-34.

Abernethy, B. (1990b). Expertise, visual search, and information pick-up in squash. *Perception, 19*, 233-252.

Abernethy, B., Farrow, D., Gorman, A. D., & Mann, D. L. (2012). Anticipatory behavior and expert performance. In N. J. Hodges & A. M. Williams (Eds.), *Skill Acquisition in Sport. Research, Theory and Practice.* (pp. 287-305). New York: Routledge.

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception, 30*, 232-255.

Abernethy, B., & Russell, D. G. (1987a). Expert-novice differences in an applied selective attention task. *Journal of Sport Psychology, 9*, 326-345.

Abernethy, B., & Russell, D. G. (1987b). The relationship between expertise and visual-search strategy in a racquet sport. *Human movement science, 6*, 283-319.

Abernethy, B., & Wollstein, J. (1989). *Improving anticipation in racquet sports*. Belconnen, ACT: Australian Sports Commission.

Abernethy, B., & Zawi, K. (2007). Pickup of essential kinematics underpins expert perception of movement patterns. *Journal of Motor Behavior, 39,*, 353-367.

Ace. (2005). In M. Ashby, C. McIntosh, J. Turnbull, S. Wehmeier, & A. S. Hornby (Eds.), *Oxford Advanced Learner's Dictionary* (7th ed.). Oxford: Oxford University Press, p. 11.

Adams, R. M. (1992). The "hot hand" revisited: Successful basketball shooting as a function of intershot interval. *Perceptual and Motor Skills, 74*, 934-934.

Adams, R. M. (1995). Momentum in the performance of professional tournament pocket billiards players. *International Journal of Sport Psychology, 26*, 580-587.

Alain, C., & Proteau, L. (1978). Etude des variables relatives au traitement de l'information en sports de raquette. *Canadian Journal of Applied Sport Sciences, 3*, 27-33.

Alain, C., & Sarrazin, C. (1990). Study of decision-making in squash competition - a computer-simulation approach. *Canadian Journal of Sport Sciences-Revue Canadienne Des Sciences Du Sport, 15*, 193-200.

Alain, C., Sarrazin, C., & Lacombe, D. (1986). The use of subjective expected values in decision-making in sport. In D. M. Landers (Ed.), *Sport and elite performers.*

The 1984 Olympic Scientific Congress Proceeding (pp. 1-7). Champaign, IL: Human Kinetics.

Albert, J., & Bennett, J. (2001). *Curve ball: Baseball, statistics, and the role of chance in the game*. New York: Copernicus.

Albright, S. C. (1993). A statistical analysis of hitting streaks in baseball. *Journal of the American Statistical Association, 88*, 1175-1183.

Alter, A. L., & Oppenheimer, D. M. (2006). From a fixation on sports to an exploration of mechanism: The past, present, and future of hot hand research. *Thinking & Reasoning, 12*, 431-444.

Anticipation. (2005). In M. Ashby, C. McIntosh, J. Turnbull, S. Wehmeier, & A. S. Hornby (Eds.), *Oxford Advanced Learner's Dictionary* (7th. ed.). Oxford: Oxford University Press, p. 56.

Avugos, S., & Bar-Eli, M. (2015). A Second Thought on the Success-Breeds-Success Model: Comment on Iso-Ahola and Dotson (2014). *Review of General Psychology, 19*, 106-111.

Ayton, P., & Fischer, I. (2004). The hot hand fallacy and the gambler's fallacy: Two faces of subjective randomness? *Memory & Cognition, 32*, 1369-1378.

Ayton, P., Hunt, A. J., & Wright, G. (1989). Psychological conceptions of randomness. *Journal of Behavioral Decision Making, 2*, 221-238.

Bakan, P. (1960). Response-tendencies in attempts to generate random binary series. *The American journal of psychology, 73*, 127-131.

Balser, N., Lorey, B., Pilgramm, S., Naumann, T., Kindermann, S., Stark, R., Zentgraf, K., Williams, A. M. & Munzert, J. (2014). The influence of expertise on brain activation of the action observation network during anticipation of tennis and volleyball serves. *Frontiers in Human Neuroscience, 8*, 1-13.

Balser, N., Lorey, B., Pilgramm, S., Stark, R., Bischoff, M., Zentgraf, K., Williams, A. M. & Munzert, J. (2014). Prediction of Human Actions: Expertise and Task-Related Effects on Neural Activation of the Action Observation Network. *Human Brain Mapping, 35*, 4016-4034.

Bar-Eli, M., Avugos, S., & Raab, M. (2006). Twenty years of "hot hand" research: Review and critique. *Psychology of Sport and Exercise, 7*, 525-553.

Bar-Hillel, M., & Wagenaar, W. A. (1991). The perception of randomness. *Advances in Applied Mathematics, 12*, 428-454.

Bar, M. (2007). The proactive brain: using analogies and associations to generate predictions. *Trends in Cognitive Sciences, 11*, 280-289.

Bard, C., & Fleury, M. (1976). Analysis of visual search activity during sport problem situations. *Journal of Human Movement Studies, 3*, 214-222.

Bartlett, F. C. (1947). The Measurement of Human Skill: Part II. *British Medical Journal, 1*, 877-880.

Barton, H., Jackson, R. C., & Bishop, D. (2013). Knowledge of player tendencies: The effect on anticipation skill and susceptibility to deception. *Journal of Sport & Exercise Psychology, 35*, 18.

Bassili, J. N. (1978). Facial motion in the perception of faces and of emotional expression. *Journal of Experimental Psychology: Human Perception and Performance, 4*, 373-379.

Betsch, C. (2004). Präferenz für Intuition und Deliberation (PID). *Zeitschrift für Differentielle und Diagnostische Psychologie, 25*, 179-197.

Betsch, C. (2008). Chronic preferences for intuition and deliberation in decision making. Lessons learned about intuition from an individual differences approach. In H. Plessner, C. Betsch, & T. Betsch (Eds.), *Intuition in judgement and decision making* (pp. 231-248). New York: Taylor & Francis Group.

Binary. (2010). In Stevenson, A. (Ed.), *Oxford Dictionary of English (3rd ed.).* Oxford: Oxford University Press, p. 166.

Bodley, H. (2011). DiMaggio's hitting streak baseball's Holy Grail. Retrieved from http://m.mlb.com/news/article/19095340/.

Boynton, D. M. (2003). Superstitious responding and frequency matching in the positive bias and gambler's fallacy effects. *Organizational Behavior and Human Decision Processes, 91*, 119-127.

Braithwaite, J. J., & Humphreys, G. W. (2003). Inhibition and anticipation in visual search: Evidence from effects of color foreknowledge on preview search. *Perception & Psychophysics, 65*, 213-237.

Braun, S., & Schmidt, U. (2015). The gambler's fallacy in penalty shootouts. *Current Biology, 25*, 597-598.

Bubic, A., von Cramon, D. Y., & Schubotz, R. I. (2010). Prediction, cognition and the brain. *Frontiers in Human Neuroscience, 4*, 15.

Buckolz, E., Prapavesis, H., & Fairs, J. (1988). Advance cues and their use in predicting tennis passing shots. *Canadian Journal of Sport Sciences-Revue Canadienne Des Sciences Du Sport, 13*, 20-30.

Burns, B. D., & Corpus, B. (2004). Randomness and inductions from streaks: "Gambler's fallacy" versus "hot hand". *Psychonomic Bulletin & Review, 11*, 179-184.

Büsch, D., Schorer, J., & Raab, M. (2016). Taktik und Taktiktraining. In K. Hottenrott & I. Seidel (Eds.), *Handbuch Trainingswissenschaft (in press)*. Schorndorf: Hofmann.

Cañal-Bruland, R. (2007). *Aufmerksamkeitsfokus und visuelle Selektion im Sport.* (Doctoral dissertation), Westfälische Wilhelms-Universität zu Münster, Münster.

Cañal-Bruland, R., Filius, M. A., & Oudejans, R. R. D. (2014). Sitting on a fastball. *Journal of Motor Behavior*, 1-4.

Cañal-Bruland, R., Filius, M. A., & Oudejans, R. R. D. (2015). Sitting on a Fastball. *Journal of Motor Behavior, 47*, 267-270.

Cañal-Bruland, R., Kreinbucher, C., & Oudejans, R. R. D. (2012). Motor expertise influences strike and ball judgements in baseball. *International Journal of Sport Psychology, 43*, 137-152.

Cañal-Bruland, R., & Mann, D. L. (2015). Time to broaden the scope of research on anticipatory behavior: a case for the role of probabilistic information. *Frontiers in Psychology, 6*, 1-3.

Cañal-Bruland, R., & Schmidt, M. (2009). Response bias in judging deceptive movements. *Acta psychologica, 130*, 235-240.

Cañal-Bruland, R., & Williams, A. M. (2010). Recognizing and Predicting Movement Effects Identifying Critical Movement Features. *Experimental Psychology, 57*, 320-326.

Canfield, R. L., & Haith, M. M. (1991). Young infants' visual expectations for symmetric and asymmetric stimulus sequences. *Developmental Psychology, 27*, 198-208.

Caruso, E. M., Waytz, A., & Epley, N. (2010). The intentional mind and the hot hand: Perceiving intentions makes streaks seem likely to continue. *Cognition, 116*, 149-153.

Cauraugh, J. H., & Janelle, C. M. (2002). Visual search and cue utilization in racket sports. In K. Davids & G. Savelsberg (Eds.), *Interceptive actions in sport* (pp. 64-89). London: Taylor & Francis.

Chiappori, P. A., Levitt, S., & Groseclose, T. (2002). Testing mixed-strategy equilibria when players are heterogeneous: The case of penalty kicks in soccer. *American Economic Review, 92*, 1138-1151.

Cisek, P. (2007). Cortical mechanisms of action selection: the affordance competition hypothesis. *Philosophical Transactions of the Royal Society B-Biological Sciences, 362*, 1585-1599.

Clark, R. D. (2003a). An analysis of streaky performance on the LPGA Tour. *Perceptual and Motor Skills, 97*, 365-370.

Clark, R. D. (2003b). Streakiness among professional golfers: Fact or fiction? *International Journal of Sport Psychology, 34*, 63-79.

Clark, R. D. (2004). On the independence of golf scores for professional golfers. *Perceptual and Motor Skills, 98*, 675-681.

Clark, R. D. (2005). Examination of hole-to-hole streakiness on the PGA tour. *Perceptual and Motor Skills, 100*, 806-814.

Cocks, A. J., Jackson, R. C., Bishop, D. T., & Williams, A. M. (2015). Anxiety, anticipation and contextual information: A test of attentional control theory. *Cognition and Emotion, 25*, 1-12.

Crognier, L., & Féry, Y. A. (2005). Effect of tactical initiative on predicting passing shots in tennis. *Applied Cognitive Psychology, 19*, 637-649.

Cross, R., & Pollard, G. (2009). Grand Slam men's singles tennis 1991-2009: serve speeds and other related data. *ITF Coaching and Sport Science Review, 16*, 8-10.

Cumming, G. (2012). *Understanding the new statistics. Effect sizes, confidence intervals, and meta-analysis*. New York: Routledge.

Cutting, J. E. (1986). *Perception with an eye for motion*. Cambridge MA.: MIT Press.

de Lussanet, M. H. E., Smeets, J. B. J., & Brenner, E. (2001). The effect of expectations on hitting moving targets: influence of the preceding target's speed. *Experimental Brain Research, 137*, 246-248.

de Lussanet, M. H. E., Smeets, J. B. J., & Brenner, E. (2002). The relation between task history and movement strategy. *Behavioural Brain Research, 129*, 51-59.

Deutscher Tennis Bund. (2004). *Tennis-Lehrplan. Band 2: Unterricht & Training*. München: BLV Verlag.

Di Russo, F., Taddei, F., Apnile, T., & Spinelli, D. (2006). Neural correlates of fast stimulus discrimination and response selection in top-level fencers. *Neuroscience Letters, 408*, 113-118.

Dicks, M., Davids, K., & Button, C. (2010). Individual differences in the visual control of intercepting a penalty kick in association football. *Human movement science, 29*, 401-411.

Dittrich, W. H. (1993). Action categories and the perception of biological motion. *Perception, 22*, 15-22.

Dorsey-Palmateer, R., & Smith, G. (2004). Bowlers' hot hands. *American Statistician, 58*, 38-45.

Duchowski, A. T. (2007). *Eye Tracking Methodology. Theory and Practice.* (Second ed.). London: Springer-Verlag.

Englisch Oxford Living Dictionaries. Random. Retrieved from https://en.oxforddictionaries.com/definition/random.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working-memory. *Psychological Review, 102*, 211-245.

Falk, R. (1975). *Peception of randomness.* (Doctoral dissertation), Hebrew University of Jerusalem, Jerusalem, Israel.

Falk, R. (1981). *The perception of randomness.* Paper presented at the Fifth International Conference for the Psychology of Mathematics Education, Grenoble, France.

Falk, R., & Konold, C. (1997). Making sense of randomness: Implicit encoding as a basis for judgment. *Psychological Review, 104*, 301-318.

Farrow, D., & Abernethy, B. (2003). Do expertise and the degree of perception - action coupling affect natural anticipatory performance? *Perception, 32*, 1127-1139.

Farrow, D., Abernethy, B., & Jackson, R. C. (2005). Probing expert anticipation with the temporal occlusion paradigm: Experimental investigations of some methodological issues. *Motor Control, 9*, 332-351.

Farrow, D., & Reid, M. (2012). The contribution of situational probability information to anticipatory skill. *Journal of Science and Medicine in Sport, 15*, 368-373.

Federer, R. (2011, 3rd of August). I'm Really Close to Making Something Special Happen. Retrieved from https://www.tennis-x.com/xblog/2011-08-03/7619.php.

Feller, W. (1950). *An introduction to probability theory and its applications*. New York: Wiley.

Féry, Y. A., & Crognier, L. (2001). On the tactical significance of game situations in anticipating ball trajectories in tennis. *Research Quarterly for Exercise and Sport, 72*, 143-149.

Forthofer, R. (1991). Streak shooter - The sequel. *Chance, 4*, 46-48.

Frame, D., Hughson, E., & Leach, J. C. (2003). Runs, regimes, and rationality: The hot hand strikes back. Working paper.

Frohlich, C. (1994). Baseball: Pitching No-Hitters. *Chance, 7*, 24-30.

Furlong, J. (1995). The service in lawn tennis: how important is it? In T. Reilly, M. Hughes, & A. Lees (Eds.), *Science and Racket Sports* (pp. 266-271). London: Routledge.

Gatev, V. (1968). Anticipation as a Control Mechanism. In H. Drischel & N. Tiedt (Eds.), *Biokybernetik. Band 2. Materialien des I. Internationalen Symposiums "Biokybernetik" Leipzig 19. - 22. September 1967* (pp. 235-238). Leipzig: Karl-Marx-Universität.

Gilden, D. L., & Wilson, S. G. (1995). Streaks in skilled performance. *Psychonomic Bulletin & Review, 2*, 260-265.

Gillet, E., Leroy, D., Thouvarecq, R., & Stein, J.-F. (2009). A Notational Analysis of Elite Tennis Serve and Serve-Return Strategies on Slow Surface. *The Journal of Strength & Conditioning Research, 23*, 532-539.

Gilovich, T., Vallone, R., & Tversky, A. (1985). The hot hand in basketball: On the misperception of random sequences. *Cognitive Psychology, 17*, 295-314.

Goodale, M. A., & Milner, A. D. (1992). Seperate visual pathways for perception and action. *Trends in Neurosciences, 15*, 20-25.

Gould, S. J. (1989). The Streak of Streaks. *Chance, 2*, 10-16.

Goulet, C., Bard, C., & Fleury, M. (1989). Expertise differences in preparing to return a tennis serve - A visual information-processing approach. *Journal of Sport & Exercise Psychology, 11*, 382-398.

Gray, R. (2002). Behavior of college baseball players in a virtual batting task. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 1131-1148.

Gronchi, G., & Sloman, S. A. (2008). Do casual belifs influence the hot-hand and gambler's fallacy? In B. C. Love, K. McRae, & V. M. Sloutsky (Eds.), *Proceedings of the 30th Annual Conference of the Cognitive Science Society*. Austin, TX: Cognitive Science Society.

Güell, R. (2015). *Luis Enrique going to Munich to win*. Retrieved from http://www.fcbarcelona.com/football/first-team/detail/article/luis-enrique-not-planning-to-speculate-in-munich

Gula, B., & Raab, M. (2004). Hot hand belief and hot hand behavior: A comment on Koehler and Conley. *Journal of Sport & Exercise Psychology, 26*, 167-170.

Hagemann, N., Schorer, J., Cañal-Bruland, R., Lotz, S., & Strauss, B. (2010). Visual perception in fencing: Do the eye movements of fencers represent their information pickup? *Attention Perception & Psychophysics, 72*, 2204-2214.

Hagemann, N., & Strauss, B. (2006). Perceptual expertise in badminton players. *Zeitschrift für Psychologie, 214*, 37-47.

Hahn, U., & Warren, P. A. (2009). Perceptions of Randomness: Why Three Heads Are Better Than Four. *Psychological Review, 116*, 454-461.

Hendricks, D., Patel, J., & Zeckhauser, R. (1993). Hot hands in mutual funds: Short-run persistence of relative performance 1974-1988. *Journal of Finance, 48*, 93-130.

Herriot, P. (2013). *Attributes of memory*. London: Taylor & Francis Group.

Hoffmann, J. (1993). *Vorhersage und Erkenntnis: Die Funktion von Antizipationen in der menschlichen Verhaltenssteuerung und Wahrnehmung*. Göttingen: Hogrefe.

Hoffmann, J. (2010). Speculations on the origin of STM. *Psychologica Belgica, 50*, 175-191.

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., & van de Weijer, J. (2011). *Eye Tracking: A comprehensive guide to methods and measures*. Oxford: Oxford University Press.

Hooke, R. (1989). Basketball, Baseball, and the Null Hypothesis. *Chance, 2*(4), 35-37.

Huettel, S. A., Mack, P. B., & McCarthy, G. (2002). Perceiving patterns in random series: dynamic processing of sequence in prefrontal cortex. *Nature Neuroscience, 5*, 485-490.

Huff, D., & Geis, I. (1959). *How to take a chance*. New York: W.W. Norton.

Hughes, M., & Bartlett, R. (2002). The use of performance indicators in performance analysis. *Journal of Sports Sciences, 20*, 739–754.

Hughes, M., & Clarke, S. (1995). Surface effect on patterns of play of elite tennis players. In T. Reilly, M. Hughes, & A. Lees (Eds.), *Science and Racket Sports* (pp. 272-278). London: Routledge Chapman & Hall.

Huys, R., Smeeton, N. J., Hodges, N. J., Beek, P. J., & Williams, A. M. (2008). On the dynamic information underlying visual anticipation skill. *Perception & Psychophysics, 70*, 1217-1234.

Hyman, R. (1953). Stimulus information as a determinant of reaction time. *Journal of Experimental Psychology, 45*, 423–432.

Iso-Ahola, S. E., & Dotson, C. O. (2014). Psychological Momentum: Why Success Breeds Success. *Review of General Psychology, 18*, 19-33.

Iso-Ahola, S. E., & Dotson, C. O. (2015). Psychological Momentum - Not a Statistical but Psychological Phenomenon: Response to Commentary by Avugos and Bar-Eli (2015). *Review of General Psychology, 19*, 112-116.

Jackson, R. C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta psychologica, 123*, 355-371.

Jarvik, M. E. (1951). Probability learning and a negative recency effect in the serial anticipation of alternative symbols. *Journal of Experimental Psychology, 41*, 291-297.

Johansson, G. (1973). Visual perceptionof biological motion and a model for its analysis. *Perception & Psychophysics, 14*, 201-211.

Jones, C. M., & Miles, T. R. (1978). Use of advance cues in predicting the flight of a lawn tennis ball *Journal of Human Movement Studies, 4*, 231-235.

Kahneman, D., & Tversky, A. (1972). Subjective probability: A judgment of representativeness. *Cognitive Psychology, 3*, 430-454.

Kamide, Y. (2008). Anticipatory Processes in Sentence Processing. *Language and Linguistics Compass, 2*, 647-670.

Kinrade, N. P. (2010). *The role of dispositional reinvestment in choking during decision-making tasks in sport.* (Doctoral dissertation), Brunel University, West London.

Kinrade, N. P., Jackson, R. C., Ashford, K. J., & Bishop, D. T. (2010). Development and validation of the Decision-Specific Reinvestment Scale. *Journal of Sports Sciences, 28*, 1127-1135.

Klaassen, F., & Magnus, J. R. (2001). Are points in tennis independent and identically distributed? Evidence from a dynamic binary panel data model. *Journal of the American Statistical Association, 96*, 500-509.

Koehler, J. J., & Conley, C. A. (2003). The "hot hand" myth in professional basketball. *Journal of Sport & Exercise Psychology, 25*, 253-259.

Koeppen, J., & Raab, M. (2012). The Hot and Cold Hand in Volleyball: Individual Expertise Differences in a Video-Based Playmaker Decision Test. *Sport Psychologist, 26*, 167-185.

Kuehn, M. (2017). Taktisch clever gegen den Lauf des Gegners spielen - Auf dem falschen Fuß erwischt. Retrieved from http://www.spox.com/de/ tennisnet/ service/1706/Artikel/taktisch-clever-gegen-den-lauf-spielen-analyse.html

Kunde, W., Elsner, K., & Kiesel, A. (2007). No anticipation-no action: the role of anticipation in action and perception. *Cognitive Processing, 8*, 71-78.

LaBerge, D. (1995). *Attentional processing. The brain's art of mindfulness.* Cambridge: Harvard University Press.

Laborde, S., Dosseville, F., & Kinrade, N. P. (2014). Decision-specific reinvestment scale: An exploration of its construct validity, and association with stress and coping appraisals. *Psychology of Sport and Exercise, 15*, 238-246.

Laplace, P. S. (1951). *A philosophical essay on probabilities*. New York: Dover.

Larkey, P. D., Smith, R. A., & Kadane, J. B. (1989). It's Okay to Believe in the “Hot Hand”. *Chance, 2*, 22-30.

Le Runigo, C., Benguigui, N., & Bardy, B. N. (2010). Visuo-motor delay, infor-mation–movement coupling, and expertise in ball sports. *Journal of Sports Sciences, 28*(3), 327–337.

Lee, D. N. (1978). The functions of vision. In H. Pick & E. Saltzman (Eds.), *Modes of perceiving and processing information*. Hillsdale NJ: Lawrence Erlbaum.

Lees, A. (2003). Science and the major racket sports: a review. *Journal of Sports Science, 21*, 707-732.

Liu, H., Gomez, M. A., & Lago-Penas, C. (2015). Match Performance Profiles of Goalkeepers of Elite Football Teams. *International Journal of Sports Science & Coaching, 10*, 669-682.

Llinás, R. R. (2002). *I of the Vortex*. Cambridge: The MIT Press.

Loffing, F., Cañal-Bruland, R., & Hagemann, N. (2014). Antizipationstraining im Sport. In K. Zentgraf & J. Munzert (Eds.), *Kognitives Training im Sport* (pp. 137-160). Göttingen: Hogrefe.

Loffing, F., Hageman, N., & Strauss, B. (2010). Application of principal components analysis to ball trajectory data: A preliminary study on identifying rally patterns in professional tennis. *Journal of Sport & Exercise Psychology, 32*, 105-105.

Loffing, F., & Hagemann, N. (2014a). On-court position influcences skilled tennis players' anticipation of shot outcome. *Journal of Sport & Exercise Psychology, 36*, 14-26.

Loffing, F., & Hagemann, N. (2014b). Skill differences in visual anticipation of type of throw in team-handball penalties. *Psychology of Sport and Exercise, 15*, 260-267.

Loffing, F., Hagemann, N., & Strauß, B. (2009). The serve in professional men's tennis: Effects of players' handedness. *International Journal of Performance Analysis in Sport, 9*, 255-274.

Loffing, F., Hagemann, N., & Strauss, B. (2010). Automated processes in tennis: Do left-handed players benefit from the tactical preferences of their opponents? *Journal of Sports Sciences, 28*, 435–443.

Loffing, F., Sölter, F., Hagemann, N., & Strauss, B. (2016). On-court position and handedness in visual anticipation of stroke direction in tennis. *Psychology of Sport and Exercise, 27*, 195-204.

Loffing, F., Stern, R., & Hagemann, N. (2015). Pattern-induced expectation bias in visual anticipation of action outcomes. *Acta psychologica, 161*, 45-53.

Loffing, F., Stern, R., & Hagemann, N. (2016). Opponents' action preferences affect action outcome anticipation in team-handball goalkeeping: A replication with novices. *Journal of Sport & Exercise Psychology, 38*, 23.

Loffing, F., Wilkes, T., & Hagemann, N. (2011). Skill Level and Graphical Detail Shape Perceptual Judgments in Tennis. *Perception, 40*, 1447-1456.

Lopes, L. L., & Oden, G. C. (1987). Distinguishing between random and nonrandom events. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 392-400.

Magnus, J. R., & Klaassen, F. J. (1999). On the advantage of serving first in a tennis set: four years at Wimbledon. *Journal of the Royal Statistical Society: Series D (The Statistician), 48*, 247-256.

Mahlo, F. (1965). Theoretische Probleme bei der taktischen Ausbildung in den Sportspielen. *Theorie und Praxis der Körperkultur, 14*(9), 809-815.

Mahlo, F. (1969). *Tactical action in play*. Paris: Vigot Freres.

Mann, D. L., Abernethy, B., & Farrow, D. (2010). Action specificity increases anticipatory performance and the expert advantage in natural interceptive tasks. *Acta psychologica, 135*, 17-23.

Mann, D. L., Schaefers, T., & Cañal-Bruland, R. (2014). Action preferences and the anticipation of action outcomes. *Acta psychologica, 152*, 1-9.

Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport & Exercise Psychology, 29*, 457-478.

Marey, E. J. (1895/1972). *Movement*. New York: Arno press.

Martinez-Gallego, R., Guzman, J. F., James, N., Pers, J., Ramon-Llin, J., & Vuckovic, G. (2013). Movement Characteristics of Elite Tennis Players on Hard Courts with Respect to the Direction of Ground Strokes. *Journal of Sports Science and Medicine, 12*, 275-281.

Martinez-Gallego, R., Guzman, J. F., Ramon-Llin, J., Crespo, M., & Vuckovic, G. (2013). The relationship between the incidence of winners/errors and the time spent in different areas of the court in elite tennis. *Journal of Human Sports & Excercise, 8*, 601-607.

Matthews, L., & Sanders, W. (1984). Effects of casual and noncasual sequences of information on subjective prediction. *Psychological Reports, 54*, 211-215.

McClelland, G. H., & Hackenberg, B. H. (1978). Subjective probabilities for sex of next child: U.S. college students and Philippine villagers. *Journal of Population, 1*, 132-147.

McKenna, F. P., & Horswill, M. S. (1999). Hazard Perception and its relevance for driver licensing. *IATSS Research, 23*, 36-41.

McPherson, S. L. (1993). The influence of player experience on problem-solving during batting preparation in baseball. *Journal of Sport & Exercise Psychology, 15*, 304-325.

McPherson, S. L. (1999a). Expert-novice differences in performance skills and problem representations of youth and adults during tennis competition. *Research Quarterly for Exercise and Sport, 70*, 233-251.

McPherson, S. L. (1999b). Tactical differences in problem representations and solutions in collegiate varsity and beginner female tennis players. *Research Quarterly for Exercise and Sport, 70*, 369-384.

McPherson, S. L. (2000). Expert-novice differences in planning strategies during collegiate singles tennis competition. *Journal of Sport & Exercise Psychology, 22*, 39-62.

McRobert, A. P., Ward, P., Eccles, D. W., & Williams, A. M. (2011). The effect of manipulating context-specific information on perceptual-cognitive processes during a simulated anticipation task. *British Journal of Psychology, 102*, 519-534.

McRobert, A. P., Williams, A. M., Ward, P., Eccles, D. W., & Ericsson, K. A. (2007). Contextual information and anticipation skill in cricket batting. *Journal of Sport & Exercise Psychology, 29*, 187.

Metzger, M. A. (1985). Biases in betting: An application of laboratory findings. *Psychological Reports, 56*, 883-888.

Miki, H., Tsuchiya, H., & Nishino, A. (1993). Influence of expectancy of opponents' competence upon information processing of their discrete attributes. *Perceptual and Motor Skills, 77*, 987-993.

Milgram, P. (1987). A spectacle-mounted liquid-crystal tachistoscope. *Behavior Research Methods Instruments & Computers, 19*, 449-456.

Miller, S., & Weinberg, R. (1991). Perceptions of psychological momentum and their relationship to performance. *The Sport Psychologist, 5*, 211-222.

Misirlisoy, E., & Haggard, P. (2014). Asymmetric Predictability and Cognitive Competition in Football Penalty Shootouts. *Current Biology, 24*, 1918-1922.

Morrison, D. G., & Schmittlein, D. C. (1998). It takes a hot goalie to raise the Stanley Cup. *Chance, 11*, 3-7.

Mueller, S., & Abernethy, B. (2006). Batting with occluded vision: An in situ examination of the information pick-up and interceptive skills of high- and low-skilled cricket batsmen. *Journal of Science and Medicine in Sport, 9*, 446-458.

Mueller, S., Abernethy, B., & Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *Quarterly Journal of Experimental Psychology, 59*, 2162-2186.

Murphy, C. P., Jackson, R. C., Cooke, K., Roca, A., Benguigui, N., & Williams, A. M. (2016). Contextual information and perceptual-cognitive expertise in a dynamic, temporally-constrained task. *Journal of Experimental Psychology: Applied, 22*, 455-470.

Navia, J. A., van der Kamp, J., & Ruiz, L. M. (2013). On the use of situation and body information in goalkeeper actions during a soccer penalty kick. *International Journal of Sport Psychology, 44*, 234-251.

Neumaier, A. (1985). Zu den Chancen des Returnspielers beim Tennisaufschlag. *Leistungssport, 15*, 5-8.

Neumaier, A., te Poel, H.-D., & Standtke, V. (1987). Zu Antizipation des Elfmetertorschusses aus Sicht des Torwarts. *Leistungssport, 17*, 23-32.

Neuringer, A. (1986). Can people behave randomly? The role of feedback. *Journal of Experimental Psychology: General, 115*, 62-75.

Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), *Motor development in children: aspects of coordination and control* (pp. 341-361). Amsterdam: Martin Nijhoff.

Nguyen, K. SMT Quick Tip #3: Wrong-Footing Your Opponent. Retrieved from https://simplemoderntennis.wordpress.com/2015/09/03/smt-quick-tip-3-how-to-wrong-foot-your-opponent/

Nickerson, R. S. (2002). The production and perception of randomness. *Psychological Review, 109*, 330-357.

North, J. S., Ward, P., Ericsson, A., & Williams, A. M. (2011). Mechanisms underlying skilled anticipation and recognition in a dynamic and temporally constrained domain. *Memory, 19*, 155-168.

Oskarsson, A. T., Van Boven, L., McClelland, G. H., & Hastie, R. (2009). What's Next? Judging Sequences of Binary Events. *Psychological Bulletin, 135*, 262-285.

Palacios-Huerta, I. (2003). Professionals play minimax. *Review of Economic Studies, 70*, 395-415.

Panchuk, D., & Vickers, J. N. (2009). Using spatial occlusion to explore the control strategies used in rapid interceptive actions: Predictive or prospective control? *Journal of Sports Sciences, 27*, 1249-1260.

Paull, G., & Glencross, D. (1997). Expert perception and decision making in baseball. *International Journal of Sport Psychology, 28*, 35-56.

Pezzulo, G., Butz, M. V., & Castelfranchi, C. (2008). The Anticipatory Approach: Definitions and Taxonomies. In G. Pezzulo, M. V. Butz, C. Castelfranchi, & R. Falcone (Eds.), *The Challenge of Anticipation: A Unifying Framework for the Analysis and Design of Artificial Cognitive Systems* (pp. 23-43). Berlin: Springer.

Pezzulo, G., Hoffmann, J., & Falcone, R. (2007). Anticipation and anticipatory behavior. *Cognitive Processing, 8*, 67-70.

Poizner, H., Bellugi, U., & Lutesdriscoll, V. (1981). Perception of american sign language in dynamic point-light displays. *Journal of Experimental Psychology: Human Perception and Performance, 7*, 430-440.

Pollick, F. E., Kay, J. W., Heim, K., & Stringer, R. (2005). Gender recognition from point-light walkers. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 1247-1265.

Proteau, L., Levesque, L., Laurencelle, L., & Girouard, Y. (1989). Decision-Making in Sport - The Effect of Stimulus-Response Probability on the Performance of a Coincidence-Anticipation Task. *Research Quarterly for Exercise and Sport, 60*, 66-76.

Raab, M. (2002). Hot hand in sports - The belief in hot hand of spectators in volleyball. In M. Koskolou, N. Geladas, & V. Klissouras (Eds.), *ECSS Proceedings: Vol. 2 seventh congress of the European Congress of sport sciences* (pp. 971). Athens: Trepoleos.

Raab, M. (2007). Think SMART, not hard. *Physical Education and Sport Pedagogy, 12*, 1-22.

Raab, M. (2015). SMART-ER: a Situation Model of Anticipated Response consequences in Tactical decisions in skill acquisition - Extended and Revised. *Frontiers in Psychology, 5*, 1-5.

Raab, M., Gula, B., & Gigerenzer, G. (2012). The Hot Hand Exists in Volleyball and Is Used for Allocation Decisions. *Journal of Experimental Psychology: Applied, 18*, 81-94.

Rapoport, A., & Budescu, D. V. (1992). Generation of random series in 2-person strictly competitive games. *Journal of Experimental Psychology: General, 121*, 352-363.

Rapoport, A., & Budescu, D. V. (1997). Randomization in individual choice behavior. *Psychological Review, 104*, 603-617.

Reichenbach, H. (1949). *The theory of probability* (E. Hutten & M. Reichenbach, Trans.). Berkeley: University of California Press.

Richardson, P. A., Adler, W., & Hankes, D. (1988). Game, set, match: Psychological momentum in tennis. *The Sport Psychologist, 2*(1), 69-76.

Riedel, C. (2013). Die schnellste Sportart der Welt – Temporekorde im Sport Retrieved from http://www.netzathleten.de/lifestyle/sports-inside/item/3523-die-schnellste-sportart-der-welt-temporekorde-im-sport

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2011). Identifying the processes underpinning anticipation and decision-making in a dynamic time-constrained task. *Cognitive Processing, 12*, 301-310.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-Cognitive Skills and Their Interaction as a Function of Task Constraints in Soccer. *Journal of Sport & Exercise Psychology, 35*, 144-155.

Roca, A., & Williams, A. M. (2016). Expertise and the Interaction between Different Perceptual-Cognitive Skills: Implications for Testing and Training. *Frontiers in Psychology, 7*, 1-4.

Rowe, R. M., & McKenna, F. P. (2001). Skilled anticipation in real-world tasks: measurement of attentional demands in the domain of tennis. *Journal of Experimental Psychology: Applied, 7*, 60–67.

Savelsbergh, G. J. P., Van der Kamp, J., Williams, A. M., & Ward, P. (2005). Anticipation and visual search behaviour in expert soccer goalkeepers. *Ergonomics, 48*, 1686-1697.

Savelsbergh, G. J. P., Williams, A. M., Van der Kamp, J., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of Sports Sciences, 20*, 279-287.

Schlaeppi-Lienhard, O., & Hossner, E.-J. (2015). Decision making in beach volleyball defense: Crucial factors derived from interviews with top-level experts. *Psychology of Sport and Exercise, 16*, 60-73.

Schlaeppi, O., Urfer, J., & Kredel, R. (2016). Visual perception in alpine ski racing : a qualitative analysis based on interviews with top-level athletes. *Sportwissenschaft, 46*, 201-212.

Schnabel, G., & Thiess, G. (1993). Antizipation *Lexikon Sportwissenschaft: Leistung - Training - Wettkampf 2, L - Z.* . Berlin: Sportverlag.

Shim, J., Carlton, L. G., Chow, J. W., & Chae, W.-S. (2005). The Use of Anticipatory Visual Cues by Highly Skilled Tennis Players. *Journal of Motor Behavior, 37*, 164-175.

Silva, J. M., Hardy, C. J., & Crace, R. K. (1988). Analysis of psychological momentum in intercollegiate tennis. *Journal of Sport & Exercise Psychology, 10*, 346-354.

Singer, R. N., Cauraugh, J. H., Chen, D., & Steinberg, G. M. (1996). Visual search, anticipation, and reactive comparisons between highly-skilled and beginning tennis players. *Journal of Applied Sport Psychology, 8*, 9-26.

Siwoff, S., Hirdt, S., & Hirdt, P. (1988). *The 1988 Elias Baseball Analyst*. New York: Collier Books.

Smith, G. (2003). Horseshoe pitchers' hot hands. *Psychonomic Bulletin & Review, 10*, 753-758.

Spektrum Akademischer Verlag. (2011). Blickbewegungsregistrierung. Retrieved from http://www.spektrum.de/lexikon/kartographiegeomatik/blickbewegungsregistrierung/598

Starkes, J. L., Edwards, P., Dissanayake, P., & Dunn, T. (1995). A new technology and field-test of advance cue usage in volleyball. *Research Quarterly for Exercise and Sport, 66*, 162-167.

Stauffler, R. (2010). *Roger Federer: Quest for Perfection.* New York: New Chapter Press.

Stern, H. S. (1995). Who's hot and who's not: Runs of success and failure in sports. *1995 Proceedings of the section on statistics in sports* (pp. 26-35): American Statistical Association.

Strack, G., Kaufmann, C., Kehrer, S., Brandt, S., & Sturmer, B. (2013). Anticipatory regulation of action control in a Simon task: behavioral, electrophysiological, and fMRI correlates. *Frontiers in Psychology, 4*, 14.

Summerfield, C., & Egner, T. (2009). Expectation (and attention) in visual cognition. *Trends in Cognitive Sciences, 13*, 403-409.

Sun, Y., & Wang, H. (2010). Gambler's fallacy, hot hand belief, and the time of patterns. *Judgment and Decision Making, 5*, 124-132.

Tolan, M. (2010, 26th September, 8:30). Schwarze Löcher gibt’s überall - Physik und Alltag [Radio transmission manuscript]. *SWR2 AULA*.

Treisman, M., & Faulkner, A. (1990). Generation of random sequences by human subjects: Cognitive operations or psychophysical process? *Journal of Experimental Psychology: General, 116*, 337-355.

Tune, G. S. (1964). Response preferences: A review of some relevant literature. *Psychological Bulletin, 61*, 286-302.

Tversky, A., & Gilovich, T. (1989a). The cold facts about the "hot hand" in basketball. *Chance, 3*, 6-7.

Tversky, A., & Gilovich, T. (1989b). The “Hot Hand”: Statistical Reality or Cognitive Illusion? *Chance, 2*, 31-34.

Tversky, A., & Kahneman, D. (1971). Belief in the law of small numbers. *Psychological Bulletin, 76*, 105-110.

USAToday. (2005). 10 Hardest things to do in sports. Retrieved from http://usatoday30.usatoday.com/sports/ten-hardest-splash.htm

van der Hulst, M., Meijman, T., & Rothengatter, T. (1999). Anticipation and the adaptive control of safety margins in driving. *Ergonomics, 42*, 336-345.

Van der Kamp, J. (2006). A field simulation study of the effectiveness of penalty kick strategies in soccer: Late alterations of kick direction increase errors and reduce accuracy. *Journal of Sports Sciences, 24*, 467-477.

Van der Kamp, J., Rivas, F., Van Doorn, H., & Savelsbergh, G. (2008). Ventral and dorsal system contributions to visual anticipation in fast ball sports. *International Journal of Sport Psychology, 39*, 100-130.

Vergin, R. (2000). Winning streaks in sports and the misperception of momentum. *Journal of Sport Behavior, 23*, 181-197.

Vesper, A. (2015). Putting the "hot hand" on ice. *Chance, 28*, 13-18.

Wagenaar, W. A. (1972). Generation of random sequences by human subjects. A critical survey of literature. *Psychological Bulletin, 77*, 65-72.

Walker, M., & Wooders, J. (2001). Minimax play at Wimbledon. *American Economic Review, 91*, 1521-1538.

Wardrop, R. L. (1999). Statistical tests for the hot-hand in basketball in a controlled setting. Retrieved from http://www.stat.wisc.edu/~wardrop/papers/tr1007.pdf

Widmaier, H. (1987). *Situative Antizipation im Sportspiel*. Frankfurt am Main: Harri Deutsch.

Williams, A. M. (2009). Perceiving the intentions of others: how do skilled performers make anticipation judgments? In M. Raab, J. G. Johnson, & H. R. Heekeren (Eds.), *Mind and Motion: The Bidirectional Link between Thought and Action* (Vol. 174, pp. 73-83).

Williams, A. M., & Burwitz, L. (1993). Advance Cue Utilization in Soccer. In T. P. Reilly, J. Clarys, & A. Stibbe (Eds.), *Science and football 2* (pp. 239-244). London: E. & F.N. Spon.

Williams, A. M., & Davids, K. (1997). Assessing cue usage in performance contexts: A comparison between eye-movement and concurrent verbal report methods. *Behavior Research Methods Instruments & Computers, 29*, 364-375.

Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport, 69*, 111-128.

Williams, A. M., & Ford, P. R. (2013). 'Game intelligence': anticipation and decision making. In A. M. Williams (Ed.), *Science and Soccer: Developing Elite Performers* (pp. 105-121). New York: Routledge.

Williams, A. M., Ford, P. R., Eccles, D. W., & Ward, P. (2011). Perceptual-Cognitive Expertise in Sport and its Acquisition: Implications for Applied Cognitive Psychology. *Applied Cognitive Psychology, 25*, 432-442.

Williams, A. M., Huys, R., Cañal-Bruland, R., & Hagemann, N. (2009). The dynamical information underpinning anticipation skill. *Human movement science, 28*, 362-370.

Williams, A. M., Ward, P., Knowles, J. M., & Smeeton, N. J. (2002). Anticipation skill in a real-world task: Measurement, training, and transfer in tennis. *Journal of Experimental Psychology: Applied, 8*, 259-270.

Williams, T., & Underwood, J. (1970). *The science of hitting*. New York: Simon & Schuster.

Wright, M. J., Bishop, D. T., Jackson, R. C., & Abernethy, B. (2011). Cortical fMRI activation to opponents' body kinematics in sport-related anticipation: Expert-novice differences with normal and point-light video. *Neuroscience Letters, 500*, 216-221.

Wright, M. J., & Jackson, R. (2006). Brain regions concerned with anticipatory skills in tennis: An fMRI. *Journal of Psychophysiology, 20*, 334-334.

Yarrow, K., Brown, P., & Krakauer, J. W. (2009). Inside the brain of an elite athlete: the neural processes that support high achievement in sports. *Nature Reviews Neuroscience, 10*, 585-596.

APPENDICES

UNIKASSEL VERSITÄT — Institut für Sport und Sportwissenschaft

Allgemeine Teilnehmer(innen)informationen über die Untersuchung

Titel der Studie: Antizipation von Tennisaufschlägen
Projektleitung: Ricarda Stern
Ansprechpartner für eventuelle Rückfragen: (Versuchsleitung) Ricarda Stern

Herzlich willkommen zu unserer Studie „Antizipation von Tennisaufschlägen“!
Wir danken Ihnen für Ihr Interesse an dieser Studie.

Beschreibung
Die Studie untersucht, wie gut Tennisspielerinnen und Tennisspieler sowie Personen ohne Erfahrung im Tennis die Richtung von Tennisaufschlägen vorhersagen können.
In dem Experiment werden Videos von Tennisaufschlägen auf einem Notebookmonitor präsentiert. Die Videos brechen im Moment des Schläger-Ball-Kontakts ab und die Aufgabe der Teilnehmerinnen und Teilnehmer ist es, die Richtung des Ballflugs (links vs. rechts) aus ihrer Sicht vorherzusagen.
Nähere Informationen zum Ablauf und zu Ihrer Aufgabe erhalten Sie auf einem gesonderten Informationsblatt. Sollten Sie darüberhinausgehende Fragen haben, wenden Sie sich damit bitte an die Versuchsleitung.
Nach Abschluss des Experiments werden Sie gebeten einen Fragebogen auszufüllen. Die komplette Testung (Experiment und Fragebogen) dauert ca. 60 Minuten.

Freiwilligkeit und Anonymität
Die Teilnahme an der Studie ist freiwillig. Sie können jederzeit und ohne Angabe von Gründen Ihre Einwilligung zur Teilnahme an dieser Studie widerrufen, ohne dass Ihnen daraus Nachteile entstehen.
Die im Rahmen dieser Studie erhobenen Daten und persönlichen Mitteilungen werden vertraulich behandelt. Diejenigen Mitarbeiterinnen und Mitarbeiter, die durch direkten Kontakt mit Ihnen über personenbezogene Daten verfügen, unterliegen der Schweigepflicht. Ihre Antworten und Ergebnisse werden nicht unter Ihrem Namen, sondern unter einer Nummer abgespeichert (siehe Datenschutz). Ihnen ist bewusst, dass die Ergebnisse der Studie als wissenschaftliche Publikation veröffentlicht werden können. Dies geschieht in anonymisierter Form, d. h. ohne dass Ihre Daten Ihrer Person zugeordnet werden können.

Datenschutz
Die Erhebung der Daten erfolgt pseudonymisiert, d. h. in namentlich nicht gekennzeichneter Form. Ihre Antworten und Ergebnisse werden unter einer Nummer gespeichert. Es existiert eine schriftliche Kodierliste auf Papier, die Ihren Namen mit der Nummer verbindet. Eine solche Zuordnung kann für die Auswertung der Daten erforderlich sein. Die Kodierliste, die eine Zuordnung Ihres Namens zu der für Sie verwendeten Nummer erlaubt, ist nur den Projektmitarbeiterinnen und -mitarbeitern zugänglich. Sie wird in einem abschließbaren Schrank aufbewahrt und nach Abschluss der Datenerhebung vernichtet. Nach Vernichtung der Kodierliste werden die anonymisierten Daten mindestens 10 Jahre gespeichert (ein Rückschluss auf den einzelnen Probanden ist dann nicht mehr möglich). Solange die Kodierliste existiert, können Sie jederzeit die Löschung aller von Ihnen erhobenen Daten verlangen.

Vergütung
Für die Teilnahme an der Untersuchung erhalten Sie keine Vergütung.

UNIKASSEL VERSITÄT

Institut für Sport und Sportwissenschaft

Einverständniserklärung

Titel der Studie: Antizipation von Tennisaufschlägen

Projektleitung: Ricarda Stern

Ansprechpartner für eventuelle Rückfragen: (Versuchsleitung) Ricarda Stern

Ich ____ bin schriftlich über die Studie und den Versuchsablauf aufgeklärt worden. Ich habe alle Informationen vollständig gelesen und verstanden. Sofern ich Fragen zu dieser vorgesehenen Studie hatte, wurden sie von der Versuchsleitung vollständig und zu meiner Zufriedenheit beantwortet.

Risiken und Vorteile

Die Teilnahme an dem Experiment ist mit keinen Risiken oder direkten Vorteilen verbunden.

Vertraulichkeit

Alle Informationen, die sich auf teilnehmende Personen beziehen, werden in anonymisierter Form digital abgespeichert. Sie werden vertraulich behandelt und werden nur den am Experiment mitwirkenden wissenschaftlichen Mitarbeitern und Mitarbeiterinnen zugänglich sein. Die Aufzeichnung und Auswertung der Daten erfolgt pseudonymisiert, d. h. unter Verwendung einer Nummer und ohne Angabe meines Namens. Es existiert eine schriftliche Kodierliste auf Papier, die meinen Namen mit der Nummer verbindet. Die Kodierliste ist nur der Versuchsleitung zugänglich und wird nach Abschluss der Datenerhebung gelöscht. Mir ist bekannt, dass ich mein Einverständnis zur Aufbewahrung bzw. Speicherung dieser Daten widerrufen kann, ohne dass mir daraus Nachteile entstehen. Ich bin darüber informiert worden, dass ich jederzeit eine Löschung all meiner Daten verlangen kann, solange die Kodierliste existiert. Ich bin einverstanden, dass anonymisierte Daten zu Forschungszwecken weiter verwendet werden können und mindestens 10 Jahre gespeichert bleiben. Mit der beschriebenen Handhabung der erhobenen Daten bin ich einverstanden.

Abbruch des Experiments

Die Teilnehmerinnen und Teilnehmer sind nicht verpflichtet, an dem Experiment teilzunehmen und können es jederzeit verlassen. Hierdurch entstehen ihnen keine Nachteile. Die Versuchsleitung kann entscheiden, die Sitzung wegen eines Softwarefehlers oder aus einem anderen Grund abzubrechen.

Einverständniserklärung zur Teilnahme

Freiwilliges Einverständnis

Die oben aufgeführten Informationen wurden mir erklärt und meine Fragen dazu wurden beantwortet. Ich weiß, dass zukünftige Fragen ebenso von der Versuchsleitung beantwortet werden. Mit meiner Unterschrift bestätige ich, dass ich an dem beschriebenen Experiment teilnehmen möchte. Eine Ausfertigung dieser Einverständniserklärung habe ich erhalten.

Ort, Datum	Name und Unterschrift der Teilnehmerin/des Teilnehmers

Bestätigung der Versuchsleitung

Ich bestätige, dass das Ziel und die Durchführung des geplanten Experiments sowie die potentiellen Vorteile und Risiken, die damit verbunden sind, der Teilnehmerin/dem Teilnehmer erklärt wurden. Ihre Fragen dazu wurden ebenfalls beantwortet.

Ort, Datum	Name und Unterschrift der Versuchsleitung

UNIKASSEL VERSITÄT

Institut für Sport und Sportwissenschaft

VPN-Code:

(wird von der Versuchsleitung ausgefüllt)

Willkommen zur Studie „ Antizipation von Tennisaufschlägen“!

Bevor wir dem Experiment beginnen, möchten wir Sie bitten, diesen Fragebogen aufmerksam durchzugehen und alle Fragen ehrlich zu beantworten.

Sie helfen uns damit, später eine genaue und umfassende Auswertung der Daten vornehmen zu können.

Gerne erinnern wir Sie daran, dass von Ihren hier gemachten Angaben nicht auf Ihre Person zurückgeschlossen wird bzw. werden kann.

Sollte bei den nachfolgenden Fragen einmal etwas unklar sein, wenden Sie sich bitte an die Versuchsleitung.

Vielen Dank für Ihre Unterstützung!

I. Persönliche Angaben

Alter: ______________________

Geschlecht: O weiblich O männlich

Körpergröße (in cm): ______________________

Ich habe eine Sehein-schränkung: O nein O ja, korrigiert (Brille, Kontaktlinsen) O ja, nicht korrigiert

Falls „ja, nicht korrigiert“, welche Form der Einschränkung haben Sie? ______________________

Schlaghand im Tennis: O links O rechts O keine Ahnung

II. Angaben zur Wettkampferfahrung im Tennis

1. Spielen Sie aktuell wettkampfmäßig Tennis bzw. haben Sie jemals wettkampfmäßig Tennis gespielt?

   ☐ ja (noch aktiv)
   ☐ ja (ehemals aktiv)
   ☐ nein

Falls **JA**, fahren Sie bitte hier fort.
Falls **NEIN**, machen Sie bitte auf der nächsten Seite bei „*III. Angaben zu sonstigen Tenniserfahrungen*“ weiter.

2. Wie hoch ist Ihr durchschnittlicher Trainings-/Wettkampfaufwand pro Woche?

   ☐ Trainingseinheiten
   ☐ Trainingsstunden
   ☐ Wettkämpfe

3. Welche Leistungsklasse (LK) haben Sie aktuell? __________

4. Welche höchste Leistungsklasse (LK) haben Sie je gehabt? __________

5. In welcher Liga betreiben Sie Tennis aktuell? __________

6. In welcher höchsten Liga haben Sie je Tennis gespielt? __________

7. Wie lange haben Sie in der höchsten Liga gespielt bzw. wie lange spielen Sie dort schon?

   ☐ Jahre

8. Wie viele Wettkämpfe absolvieren Sie (ungefähr) pro Jahr? __________

9. Haben Sie bei internationalen Wettkämpfen gespielt?

   ☐ ja
   ☐ nein

Falls ja: Bei welchen internationalen Wettkämpfen?

____

10. Was waren Ihre bislang größten sportlichen Erfolge im Tennis?

____

11. Seit wie vielen Jahren spielen Sie nun insgesamt Tennis?

   ☐ Jahre

III. Angaben zu sonstigen Tenniserfahrungen

1. Haben Sie sonstige, nicht wettkampfmäßige Erfahrungen im Tennis gesammelt?
   - ☐ ja
   - ☐ nein

Falls ja, …

a. … in welchem Kontext? (bitte ankreuzen)
   - ☐ Schule
   - ☐ Studium
   - ☐ Verein
   - ☐ Freizeit (nicht im Verein)

b. … über welchen Zeitraum? ____________________

2. Sofern Sie Sport studieren bzw. studiert haben sollten…:

a. Haben Sie Tenniskurse im Rahmen Ihres Studiums absolviert bzw. belegen Sie derzeit welche?
   - ☐ ja
   - ☐ nein

b. Falls ja, welche Kurse haben Sie absolviert bzw. belegen Sie derzeit?
(sofern passend, setzen Sie bitte ein: a = absolviert, b = aktuell belegt)
   - ☐ Grundkurs
   - ☐ Aufbaukurs

IV. Angaben zu Erfahrungen in anderen Sportarten

Haben Sie Erfahrung in anderen Sportarten außer Tennis?
   - ☐ ja
   - ☐ nein

Falls ja, machen Sie bitte im Folgenden dazu nähere Angaben:

Sportart	Kontext (Verein, Schule, Freizeit,…)	Zeitraum	Liga (z.B. Kreisliga, Landesliga)

VPN-Code:
(wird von der Versuchsleitung ausgefüllt)

Vielen Dank für Ihre Teilnahme an der Studie!

Abschließend möchten wir Sie erneut bitten, den folgenden Fragebogen aufmerksam durchzugehen und alle Fragen ehrlich zu beantworten.

Sie helfen uns damit, später eine genaue und umfassende Auswertung der Daten vornehmen zu können.

Gerne erinnern wir Sie daran, dass von Ihren hier gemachten Angaben nicht auf Ihre Person zurückgeschlossen wird bzw. werden kann.

Sollte bei den nachfolgenden Fragen einmal etwas unklar sein, wenden Sie sich bitte an die Versuchsleitung.

Vielen Dank für Ihre Unterstützung!

V. Angaben zum Experiment

1. Haben Sie zur Lösung der im Experiment gestellten Aufgabe (Vorhersage der Aufschlagrichtung) bestimmte Strategien genutzt oder spezielle Informationsquellen einbezogen?

   O ja O nein

Falls ja, beschreiben Sie die Strategie(n) bzw. Informationsquellen bitte im Folgenden:

____

____

____

____

2. Sind Ihnen im Laufe der Untersuchung irgendwelche Besonderheiten hinsichtlich des Ablaufs oder des Inhaltes der gezeigten Videos aufgefallen?

   O ja O nein

Falls ja, benennen Sie die Besonderheiten bitte im Folgenden:

____

____

____

____

3. Bitte kreuzen Sie im Folgenden auf einer Skala von 1 (absolut unmotiviert) bis 10 (absolut motiviert) ehrlich an, wie motiviert Sie sich bei der Bearbeitung der einzelnen Experimentteile gefühlt haben.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Teil 1: Aufschlagspiel 1-16	O	O	O	O	O	O	O	O	O	O
Teil 2: Aufschlagspiel 17-32	O	O	O	O	O	O	O	O	O	O
Teil 3: Aufschlagspiel 33-48	O	O	O	O	O	O	O	O	O	O
Teil 4: Aufschlagspiel 49-64	O	O	O	O	O	O	O	O	O	O

4. Hatten Sie den Eindruck, dass in dem Experiment identische Videos mehrfach gezeigt wurden?

O ja O nein

Falls ja: In jedem Aufschlagspiel wurden Ihnen sechs Videos präsentiert. Hatten Sie den Eindruck, dass es innerhalb der Aufschlagspiele eine bestimmte Stelle gab (d.h. der 1., 2., 3., 4., 5. oder 6. Aufschlag), an der besonders oft identische Videos präsentiert wurden?

O ja O nein

Falls ja: Kreuzen Sie bitte die Aufschlagnummer an, von der Sie meinen, dass dort besonders oft identische Videos präsentiert wurden.

1.	2.	3.	4.	5.	6.
O	O	O	O	O	O

5. Hatten Sie den Eindruck, dass es innerhalb der Aufschlagspiele bestimmte Muster oder Regelhaftigkeiten in der Abfolge der gezeigten Videos gab, anhand derer man den Ausgang eines Aufschlages erkennen konnte?

O ja O nein

Falls ja, benennen Sie die Muster oder Regelhaftigkeiten bitte im Folgenden:

___

___

___

Außerdem…

Ich schätze meine Fähigkeit, einen Gegenspieler lange darüber im Unklaren zu lassen, ob ich einen Aufschlag nach links oder rechts ausführen werde, als … ein.

sehr schwach									*sehr stark*
O	O	O	O	O	O	O	O	O	O

VI. Abschließende Fragen

Im Folgenden finden Sie Aussagen über Ihre Person. Bitte lesen Sie jede Aussage genau durch. Kreuzen Sie bitte zu jeder Aussage immer die Ziffer an (von 1 = „ich stimme nicht zu“ bis 5 = „ich stimme voll zu“), die am ehesten auf Ihr Leben im Allgemeinen zutrifft.
Pro Aussage entscheiden Sie sich bitte nur für <u>eine</u> Antwortalternative. Antworten Sie bitte stets spontan und ehrlich.
Dies ist kein Test! Es gibt also keine richtigen oder falschen Antworten. Bitte beantworten Sie alle Fragen, auch wenn sich diese manchmal ähneln.

	ich stimme nicht zu 1	*2*	*3*	*4*	*ich stimme voll zu* 5
Bevor ich Entscheidungen treffe, denke ich meistens erst mal gründlich nach.	○	○	○	○	○
Ich beobachte sorgfältig meine innersten Gefühle.	○	○	○	○	○
Bevor ich Entscheidungen treffe, denke ich meistens erst mal über meine Ziele nach, die ich erreichen will.	○	○	○	○	○
Bei den meisten Entscheidungen ist es sinnvoll, sich ganz auf sein Gefühl zu verlassen.	○	○	○	○	○
Ich mag Situationen nicht, in denen ich mich auf meine Intuition verlassen muss.	○	○	○	○	○
Ich denke über mich nach.	○	○	○	○	○
Ich schmiede lieber ausgefeilte Pläne, als etwas dem Zufall zu überlassen.	○	○	○	○	○
Ich ziehe Schlussfolgerungen lieber aufgrund meiner Gefühle, Menschenkenntnis und Lebenserfahrung.	○	○	○	○	○
Bei meinen Entscheidungen spielen Gefühle eine große Rolle.	○	○	○	○	○
Ich bin perfektionistisch.	○	○	○	○	○
Wenn ich eine Entscheidung rechtfertigen muss, denke ich vorher besonders gründlich nach.	○	○	○	○	○
Wenn es darum geht, ob ich anderen vertrauen soll, entscheide ich aus dem Bauch heraus.	○	○	○	○	○
Ich nehme bei einem Problem erst mal die harten Fakten und Details auseinander, bevor ich mich entscheide.	○	○	○	○	○
Ich denke erst nach, bevor ich handle.	○	○	○	○	○
Ich mag lieber gefühlsbetonte Personen.	○	○	○	○	○
Ich denke über meine Pläne und Ziele stärker nach als andere Menschen.	○	○	○	○	○
Ich bin ein sehr intuitiver Mensch.	○	○	○	○	○
Ich mag emotionale Situationen, Diskussionen und Filme.	○	○	○	○	○

Der folgende Fragebogen enthält Aussagen, die sich darauf beziehen wie Sie im Sport Entscheidungen treffen.

Geben Sie bitte für jede Aussage an, welche Antwort charakteristisch für Ihre Art und Weise Entscheidungen zu treffen ist.

Die Antworten reichen von 0 („gar nicht charakteristisch“) bis 4 („sehr charakteristisch“).

Beantworten Sie die Aussagen bitte ehrlich. Es gibt keine richtigen oder falschen Antworten. Denken Sie nicht zu lange über die Aussagen nach.

	gar nicht charakteristisch				*sehr charakteristisch*
	0	1	2	3	4
Ich versuche immer herauszufinden, wie ich Entscheidungen treffe.	○	○	○	○	○
Meine Art, Entscheidungen zu treffen, beschäftigt mich.	○	○	○	○	○
Über schlechte Entscheidungen denke ich noch lange Zeit nach.	○	○	○	○	○
Ich überprüfe ständig die Gründe für meine Entscheidungen.	○	○	○	○	○
Ich rege mich auf, wenn ich nur an schlechte Entscheidungen denke, die ich in der Vergangenheit getroffen habe.	○	○	○	○	○
Ich habe manchmal das Gefühl, dass ich meinen Entscheidungsfindungsprozess beobachte.	○	○	○	○	○
Ich ertappe mich oft dabei, dass ich immer wieder über schlechte Entscheidungen nachdenke, die ich in der Vergangenheit getroffen	○	○	○	○	○
Ich denke über bessere Entscheidungen nach, die ich hätte treffen können, lange nachdem das Ereignis vorbei ist.	○	○	○	○	○
Ich bin aufmerksam gegenüber Veränderungen in Bezug auf die Intensität wie viel ich über meine Entscheidungen nachdenke.	○	○	○	○	○
Mir ist bewusst wie meine Entscheidungsprozesse gedanklich ablaufen.	○	○	○	○	○
Ich vergesse selten die Situationen, bei denen ich schlechte Entscheidungen getroffen habe, auch wenn es sich um unbedeutende Dinge	○	○	○	○	○
Wenn ich an schlechte Entscheidungen erinnert werde, die ich in der Vergangenheit getroffen habe, fühle ich mich als ob sie noch einmal	○	○	○	○	○
Mich beschäftigt wie andere Personen über meine Entscheidungen denken	○	○	○	○	○

Vielen Dank für Ihre Unterstützung!

ABLAUF DES EXPERIMENTS

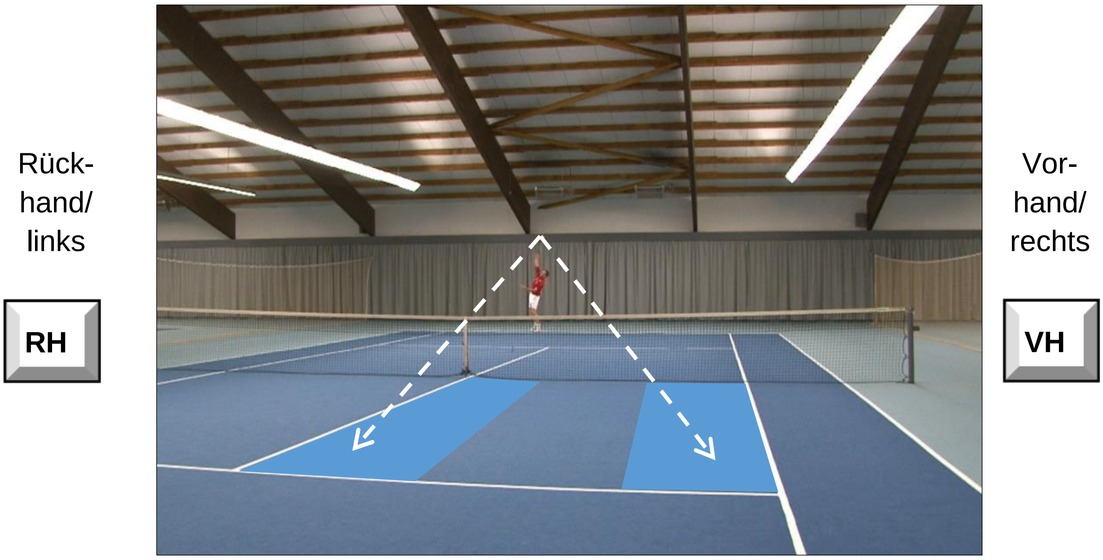
- Im folgenden Experiment werden Ihnen Videoclips von Tennisaufschlägen aus der Sicht eines Returnspielers präsentiert. Die Clips werden blockweise in Aufschlagspielen mit jeweils 6 Aufschlägen präsentiert, d.h. der Aufschläger schlägt abwechselnd von der Einstand- und Vorteilseite auf.
- Die Schläge werden aus Ihrer Sicht auf Ihre Vorhandseite (nach rechts) oder Ihre Rückhandseite (nach links) geschlagen (siehe Abbildung unten).
- Die Schläge brechen im Moment des Schläger-Ball-Kontakts ab. Nach dem Abbruch eines Videos erscheint ein schwarzer Bildschirm.
- Damit Sie eine bessere Vorstellung davon erhalten, was Sie im Experiment erwartet, haben Sie die Möglichkeit, vorab 4 Gewöhnungsversuche zu absolvieren.
- Nachdem Sie die Gewöhnungsvideos durchlaufen haben, startet das Experiment. Das Experiment enthält insgesamt 64 Aufschlagspiele, d.h. 384 Videoclips; nach jeweils 16 Aufschlagspielen gibt es eine mindestens einminütige Pause.

AUFGABE

Vorhersage der Schlagrichtung

Sobald der Bildschirm nach dem Abbruch eines Videos schwarz geworden ist, sagen Sie bitte **so genau und frühzeitig wie möglich** vorher, ob der Ball aus ihrer Sicht auf Ihre Vorhandseite (nach rechts) oder Ihre Rückhandseite (nach links) geschlagen wird (vgl. gestrichelte Linien in der Abbildung).

Um eine Entscheidung zu treffen, drücken Sie bitte eine der folgenden zwei Antworttasten (vgl. Markierung auf der Tastatur):



Nachdem Sie die Schlagrichtung vorhergesagt haben, erhalten Sie automatisch eine Rückmeldung über den tatsächlichen Ausgang eines Schlages. Die Rückmeldung erhalten Sie, indem Ihnen der Rest des zuvor gezeigten Videos, beginnend mit dem Schläger-Ball-Kontakt und bis zum Ende des sichtbaren Ballflugs, gezeigt wird.

Danach startet automatisch der nächste Versuch.

UNI KASSEL VERSITÄT

Institut für Sport und Sportwissenschaft

Information zur Einverständniserklärung[14]

Zweck
Im Rahmen von Wahrnehmungsexperimenten sollen den Versuchsteilnehmerinnen und -teilnehmern Tennisaufschläge (1. Aufschläge) auf einer Großleinwand präsentiert werden. Für die Erstellung der Wahrnehmungsexperimente wird ausreichendes Videomaterial von Tennisaufschlägen benötigt.

Ablauf der Videoaufzeichnungen
Die Spieler, deren Aufschläge aus der Perspektive eines Returnspielers mit einer Videokamera aufgezeichnet werden soll, werden gebeten, ihre 1. Aufschläge so realitätsnah wie möglich auszuführen (d.h. wie in einem Wettkampfspiel). Es sollen sowohl für die Einstand- als auch für die Vorteilseite Aufschläge aufgenommen werden. Für beide Felder werden insbesondere Aufschläge benötigt, die nach innen (d.h. die Linie entlang), nach außen (d.h. in die Nähe der Seitenauslinie) und durch die Mitte platziert werden. Von einer Person werden von jeder Seite pro Schlagrichtung mindestens 20 gültige Versuche benötigt.

Risiken und Vorteile
Bei der Durchführung der Videoaufnahmen müssen die 1. Aufschläge realitätsnah simuliert werden. Bei jeder Form körperlicher bzw. sportlicher Betätigung besteht ein Verletzungs- und Schadensrisiko. Sollten während der Aktivität spürbar/fühlbare Veränderungen im Befinden auftreten (Schmerzen, Unwohlsein, Atemnot, Schwindel, o. ä.), muss dies umgehend den Durchführenden mitgeteilt werden. Die Teilnahme an den Aufnahmen ist mit keinen direkten Vorteilen verbunden.

Vertraulichkeit und Verwendung der Daten
Selbstverständlich unterliegen Ihre Daten und die Videoaufzeichnung dem Datenschutz. Eine Nutzung der Aufnahmen kann in folgenden Bereichen erfolgen:

Forschung	Die Aufnahmen sollen primär für die Erstellung und Durchführung videobasierter Wahrnehmungsexperimente verwendet werden (vgl. Zweck oben).
Lehre	Im Rahmen experimentell ausgerichteter Lehrveranstaltungen (universitätsintern) könnten die Videosequenzen eingesetzt werden, um experimentelle Methoden und das dabei eingesetzte Videomaterial exemplarisch zu veranschaulichen. Die Videos bleiben im Besitz der an den Aufnahmen beteiligten wissenschaftlichen Mitarbeiter und werden nicht an Dritte weitergegeben.
Veröffentlichungen	Im Rahmen der Vorstellung oder Veröffentlichung von Forschungsergebnissen (z.B. auf Fachkongressen, in Fachzeitschriften) ist es u.U. notwendig, Ausschnitte aus den Videos (z.B. Screenshots) zur Veranschaulichung abzubilden. Bei der Veröffentlichung solcher Abbildungen wird darauf geachtet, dass die Anonymität der dargestellten Person gewährleistet wird.

Die Aufzeichnungen werden vertraulich behandelt und werden nur den am Projekt mitwirkenden wissenschaftlichen Mitarbeitern und Mitarbeiterinnen zugänglich sein.
Die Daten werden auf gesicherten Rechnern und in verschlossenen Räumen aufbewahrt.
Die Aufzeichnungen dienen ausdrücklich nicht der kommerziellen Nutzung.

[14] Please note that similar informed consents were used for the video recordings carried out within Study 2 and Study 3. Therefore, only the documents of Study 2 are included in the appendices. The same applies to the anamnesis form (Appendix F).

UNIKASSEL VERSITÄT

Institut für Sport und Sportwissenschaft

Name: ____________________________
Straße: ____________________________
PLZ/Wohnort: ____________________________

Einverständniserklärung zur Videoaufzeichnung

1. Ich erkläre mich damit einverstanden, dass am ____________ von mir Videoaufzeichnungen von 1. Aufschlägen im Tennis angefertigt und gespeichert werden. Die Aufzeichnungen finden in der Tennishalle der SGT Baunatal, Am Mühlenwerth, 34225 Baunatal, statt.

2. Ich erkläre mich weiterhin damit einverstanden, dass die Videoaufzeichnungen im Rahmen videobasierter Wahrnehmungsexperimente (Forschung) verwendet werden und auch für folgende Einsatzzwecke genutzt werden dürfen (nicht Zutreffendes bitte streichen):

   - Forschung
   - Lehre
   - Veröffentlichungen

3. Ich verzichte hiermit auf sämtliche Ansprüche im Hinblick auf Nutzungsrechte oder Vergütung.

Ich wurde darüber informiert, dass meine Einwilligung freiwillig ist, dass ich diese Einverständniserklärung jederzeit zurücknehmen kann und mir bei Verweigerung oder Zurücknahme der Einwilligung keine Nachteile entstehen. Eine Ausfertigung dieser Einverständniserklärung habe ich erhalten.

____________________ Ort, Datum

____________________ Unterschrift der Teilnehmerin/des Teilnehmers

Bestätigung des Mitarbeiters der Institution

Hiermit bestätige ich, dass der Teilnehmer/die Teilnehmerin über die Einverständniserklärung aufgeklärt wurde, dass er/sie in der Lage ist diese zu verstehen und dazu fähig ist, die Einwilligung zu geben.

____________________ Ort, Datum

____________________ Unterschrift der Mitarbeiterin/des Mitarbeiters

UNIKASSEL VERSITÄT

Institut für Sport und Sportwissenschaft

VPN-Code:

(wird vom Versuchsleiter ausgefüllt)

Persönliche Angaben

Alter: ____________________

Geschlecht: O weiblich O männlich

Körpergröße (in cm): ____________________

Ich habe eine Seheinschränkung: O nein O ja, korrigiert (Brille, Kontaktlinsen) O ja, nicht korrigiert

Gesundheitlicher Hintergrund

1 Hatten Sie in den letzten zwei Jahren:

- Plötzliche Ohnmachten beim Sport (Kollaps)?	O ja	O nein	Wenn ja, wann? ________
- Bewusstlosigkeit oder Schwindel beim Sport?	O ja	O nein	Wenn ja, wann? ________
- Herzschmerzen beim Sport?	O ja	O nein	Wenn ja, wann? ________
- Herzstolpern beim und nach dem Sport?	O ja	O nein	Wenn ja, wann? ________
- Ungewöhnliche Luftnot beim Sport?	O ja	O nein	Wenn ja, wann? ________

2 Haben Sie erhöhten Blutdruck? O ja O nein O unbekannt

Wenn ja, seit wann? ____________________

3 Haben Sie Beschwerden an Muskeln oder Gelenken? O ja O nein

Wenn ja, wo? ____________________

____

4 Fühlen Sie Unsicherheiten bei körperlicher Belastung? O ja O nein

5 Haben Sie irgendwelche Beschwerden? O ja O nein

Wenn ja: O Schlafstörungen O Appetitmangel O Verstopfung O Beschwerden beim Wasserlassen O sonstiges: ____________________

6 Leiden Sie unter Atembeschwerden? O ja O nein

Wenn ja: O Atemnot O Husten O Auswurf

7 Leiden Sie unter Herzschmerzen (Enge im Brustkorbbereich)? O ja O nein

8 Leiden Sie unter Allergien? O ja O nein

Wenn ja, welche? ____________________

____

9 Haben Sie in den letzten 4 Wochen deutlich an Gewicht verloren (mehr als 2 kg)? O ja O nein

10 Hatten Sie in den letzten 3 Wochen einen Infekt / eine Erkältung? O ja O nein

Medizinische Anamnese

11 Fühlen Sie sich derzeit gesund und belastbar? O ja O nein

Wenn nein, welche Beschwerden haben Sie? ________________________________

12 Fühlen Sie sich den geplanten Anforderungen in der Untersuchung gewachsen? O ja O nein

Risikofaktoren

13 Bestehen bei Ihnen gesundheitliche Risikofaktoren? O ja O nein

Wenn ja, welche? ____

Besonderheiten im Zusammenhang mit „Tennis spielen“

z. B. spezifische Einschränkungen

______________________ ____________________________________

Ort, Datum Name und Unterschrift des Teilnehmers

UNI KASSEL VERSITÄT

Institut für Sport und Sportwissenschaft

Allgemeine Teilnehmer(innen)informationen über die Untersuchung

Titel der Studie:	Antizipation von gegnerischen Grundschlägen in Tennisballwechseln
Projektleitung:	Ricarda Stern
Ansprechpartner für eventuelle Rückfragen: (Versuchsleitung)	Ricarda Stern

Herzlich willkommen zu unserer Studie „Antizipation von gegnerischen Grundschlägen in Tennisballwechseln“! Wir danken Ihnen für Ihr Interesse an dieser Studie.

Beschreibung

Die Studie untersucht, wie gut Tennisspielerinnen und Tennisspieler sowie Personen ohne Erfahrung im Tennis die Richtung von Tennisschlägen innerhalb von Ballwechseln vorhersagen können.

In dem Experiment werden Videos von Tennisballwechseln auf einem Notebookmonitor präsentiert. Die Videos werden bei jedem gegnerischen Schlag im Moment des Schläger-Ball-Kontakts unterbrochen und die Aufgabe der Teilnehmerinnen und Teilnehmer ist es, die Richtung des Ballflugs (links vs. rechts) aus ihrer Sicht vorherzusagen.

Nähere Informationen zum Ablauf und zu Ihrer Aufgabe erhalten Sie auf einem gesonderten Informationsblatt. Sollten Sie darüberhinausgehende Fragen haben, wenden Sie sich damit bitte an die Versuchsleitung.

Nach Abschluss des Experiments werden Sie gebeten einen Fragebogen auszufüllen. Die komplette Testung (Experiment und Fragebogen) dauert ca. 90 Minuten.

Freiwilligkeit und Anonymität

Die Teilnahme an der Studie ist freiwillig. Sie können jederzeit und ohne Angabe von Gründen Ihre Einwilligung zur Teilnahme an dieser Studie widerrufen, ohne dass Ihnen daraus Nachteile entstehen.

Die im Rahmen dieser Studie erhobenen Daten und persönlichen Mitteilungen werden vertraulich behandelt. Diejenigen Mitarbeiterinnen und Mitarbeiter, die durch direkten Kontakt mit Ihnen über personenbezogene Daten verfügen, unterliegen der Schweigepflicht. Ihre Antworten und Ergebnisse werden nicht unter Ihrem Namen, sondern unter einer Nummer abgespeichert (siehe Datenschutz). Ihnen ist bewusst, dass die Ergebnisse der Studie als wissenschaftliche Publikation veröffentlicht werden können. Dies geschieht in anonymisierter Form, d. h. ohne dass Ihre Daten Ihrer Person zugeordnet werden können.

Datenschutz

Die Erhebung der Daten erfolgt pseudonymisiert, d. h. in namentlich nicht gekennzeichneter Form. Ihre Antworten und Ergebnisse werden unter einer Nummer gespeichert. Es existiert eine schriftliche Kodierliste auf Papier, die Ihren Namen mit der Nummer verbindet. Eine solche Zuordnung kann für die Auswertung der Daten erforderlich sein. Die Kodierliste, die eine Zuordnung Ihres Namens zu der für Sie verwendeten Nummer erlaubt, ist nur den Projektmitarbeiterinnen und -mitarbeitern zugänglich. Sie wird in einem abschließbaren Schrank aufbewahrt und nach Abschluss der Datenerhebung vernichtet. Nach Vernichtung der Kodierliste werden die anonymisierten Daten mindestens 10 Jahre gespeichert (ein Rückschluss auf den einzelnen Probanden ist dann nicht mehr möglich). Solange die Kodierliste existiert, können Sie jederzeit die Löschung aller von Ihnen erhobenen Daten verlangen.

Vergütung

Für die Teilnahme an der Untersuchung erhalten Sie keine Vergütung.

UNIKASSEL VERSITÄT

Institut für Sport und Sportwissenschaft

Einverständniserklärung

Titel der Studie: Antizipation von gegnerischen Grundschlägen in Tennisballwechseln

Projektleitung: Ricarda Stern

Ansprechpartner für eventuelle Rückfragen: (Versuchsleitung) Ricarda Stern

Ich ____ bin schriftlich über die Studie und den Versuchsablauf aufgeklärt worden. Ich habe alle Informationen vollständig gelesen und verstanden. Sofern ich Fragen zu dieser vorgesehenen Studie hatte, wurden sie von der Versuchsleitung vollständig und zu meiner Zufriedenheit beantwortet.

Risiken und Vorteile

Die Teilnahme an dem Experiment ist mit keinen Risiken oder direkten Vorteilen verbunden.

Vertraulichkeit

Alle Informationen, die sich auf teilnehmende Personen beziehen, werden in anonymisierter Form digital abgespeichert. Sie werden vertraulich behandelt und werden nur den am Experiment mitwirkenden wissenschaftlichen Mitarbeitern und Mitarbeiterinnen zugänglich sein. Die Aufzeichnung und Auswertung der Daten erfolgt pseudonymisiert, d. h. unter Verwendung einer Nummer und ohne Angabe meines Namens. Es existiert eine schriftliche Kodierliste auf Papier, die meinen Namen mit der Nummer verbindet. Die Kodierliste ist nur der Versuchsleitung zugänglich und wird nach Abschluss der Datenerhebung gelöscht. Mir ist bekannt, dass ich mein Einverständnis zur Aufbewahrung bzw. Speicherung dieser Daten widerrufen kann, ohne dass mir daraus Nachteile entstehen. Ich bin darüber informiert worden, dass ich jederzeit eine Löschung all meiner Daten verlangen kann, solange die Kodierliste existiert. Ich bin einverstanden, dass anonymisierte Daten zu Forschungszwecken weiter verwendet werden können und mindestens 10 Jahre gespeichert bleiben. Mit der beschriebenen Handhabung der erhobenen Daten bin ich einverstanden.

Abbruch des Experiments

Die Teilnehmerinnen und Teilnehmer sind nicht verpflichtet, an dem Experiment teilzunehmen und können es jederzeit verlassen. Hierdurch entstehen ihnen keine Nachteile. Die Versuchsleitung kann entscheiden, die Sitzung wegen eines Softwarefehlers oder aus einem anderen Grund abzubrechen.

Einverständniserklärung zur Teilnahme

Freiwilliges Einverständnis

Die oben aufgeführten Informationen wurden mir erklärt und meine Fragen dazu wurden beantwortet. Ich weiß, dass zukünftige Fragen ebenso von der Versuchsleitung beantwortet werden. Mit meiner Unterschrift bestätige ich, dass ich an dem beschriebenen Experiment teilnehmen möchte. Eine Ausfertigung dieser Einverständniserklärung habe ich erhalten.

Ort, Datum	Name und Unterschrift der Teilnehmerin/des Teilnehmers

Bestätigung der Versuchsleitung

Ich bestätige, dass das Ziel und die Durchführung des geplanten Experiments sowie die potentiellen Vorteile und Risiken, die damit verbunden sind, der Teilnehmerin/dem Teilnehmer erklärt wurden. Ihre Fragen dazu wurden ebenfalls beantwortet.

Ort, Datum	Name und Unterschrift der Versuchsleitung

UNIKASSEL VERSITÄT

Institut für Sport und Sportwissenschaft

VPN-Code:
(wird von der Versuchsleitung ausgefüllt)

Willkommen zur Studie „ Antizipation von gegnerischen Grundschlägen in Tennisballwechseln“!

Bevor wir dem Experiment beginnen, möchten wir Sie bitten, diesen Fragebogen aufmerksam durchzugehen und alle Fragen ehrlich zu beantworten.
Sie helfen uns damit, später eine genaue und umfassende Auswertung der Daten vornehmen zu können.
Gerne erinnern wir Sie daran, dass von Ihren hier gemachten Angaben nicht auf Ihre Person zurückgeschlossen wird bzw. werden kann.
Sollte bei den nachfolgenden Fragen einmal etwas unklar sein, wenden Sie sich bitte an die Versuchsleitung.

Vielen Dank für Ihre Unterstützung!

I. Persönliche Angaben

Alter: ______________________

Geschlecht: O weiblich O männlich

Körpergröße (in cm): ______________________

Ich habe eine Sehein-schränkung: O nein O ja, korrigiert (Brille, Kontaktlinsen) O ja, nicht korrigiert

Falls „ja, nicht korrigiert“, welche Form der Einschränkung haben Sie? ______________________

Schlaghand im Tennis: O links O rechts O keine Ahnung

II. Angaben zur Wettkampferfahrung im Tennis

12. Spielen Sie aktuell wettkampfmäßig Tennis bzw. haben Sie jemals wettkampfmäßig Tennis gespielt?
    - ☐ ja (noch aktiv)
    - ☐ ja (ehemals aktiv)
    - ☐ nein

Falls **JA**, fahren Sie bitte hier fort.
Falls **NEIN**, machen Sie bitte auf der nächsten Seite bei *„III. Angaben zu sonstigen Tenniserfahrungen“* weiter.

13. Wie hoch ist Ihr durchschnittlicher Trainings-/Wettkampfaufwand pro Woche?
    - ☐ Trainingseinheiten
    - ☐ Trainingsstunden
    - ☐ Wettkämpfe

14. Welche Leistungsklasse (LK) haben Sie aktuell? ____________

15. Welche höchste Leistungsklasse (LK) haben Sie je gehabt? ____________

16. In welcher Liga betreiben Sie Tennis aktuell? ____________

17. In welcher höchsten Liga haben Sie je Tennis gespielt? ____________

18. Wie lange haben Sie in der höchsten Liga gespielt bzw. wie lange spielen Sie dort schon? ☐ Jahre

19. Wie viele Wettkämpfe absolvieren Sie (ungefähr) pro Jahr? ____________

20. Haben Sie bei internationalen Wettkämpfen gespielt?
    - ☐ ja
    - ☐ nein

Falls ja: Bei welchen internationalen Wettkämpfen?

____

21. Was waren Ihre bislang größten sportlichen Erfolge im Tennis?

____

22. Seit wie vielen Jahren spielen Sie nun insgesamt Tennis? ☐ Jahre

III. Angaben zu sonstigen Tenniserfahrungen

3. Haben Sie sonstige, nicht wettkampfmäßige Erfahrungen im Tennis gesammelt?

☐ ja
☐ nein

Falls ja, …

c. … in welchem Kontext? (bitte ankreuzen)

☐ Schule
☐ Studium
☐ Verein
☐ Freizeit (nicht im Verein)

d. … über welchen Zeitraum? ____________________

4. Sofern Sie Sport studieren bzw. studiert haben sollten…:

c. Haben Sie Tenniskurse im Rahmen Ihres Studiums absolviert bzw. belegen Sie derzeit welche?

☐ ja
☐ nein

d. Falls ja, welche Kurse haben Sie absolviert bzw. belegen Sie derzeit?
(sofern passend, setzen Sie bitte ein: a = absolviert, b = aktuell belegt)

☐ Grundkurs
☐ Aufbaukurs

IV. Angaben zu Erfahrungen in anderen Sportarten

Haben Sie Erfahrung in anderen Sportarten außer Tennis?

☐ ja
☐ nein

Falls ja, machen Sie bitte im Folgenden dazu nähere Angaben:

Sportart	Kontext (Verein, Schule, Freizeit,…)	Zeitraum	Liga (z.B. Kreisliga, Landesliga)

VPN-Code:

(wird von der Versuchsleitung ausgefüllt)

Vielen Dank für Ihre Teilnahme an der Studie!

Abschließend möchten wir Sie erneut bitten, den folgenden Fragebogen aufmerksam durchzugehen und alle Fragen ehrlich zu beantworten.
Sie helfen uns damit, später eine genaue und umfassende Auswertung der Daten vornehmen zu können.
Gerne erinnern wir Sie daran, dass von Ihren hier gemachten Angaben nicht auf Ihre Person zurückgeschlossen wird bzw. werden kann.
Sollte bei den nachfolgenden Fragen einmal etwas unklar sein, wenden Sie sich bitte an die Versuchsleitung.

Vielen Dank für Ihre Unterstützung!

V. Angaben zum Experiment

1. Haben Sie zur Lösung der im Experiment gestellten Aufgabe (Vorhersage der gegnerischen Schlagrichtung)
bestimmte Strategien genutzt oder spezielle Informationsquellen einbezogen?

O ja O nein

Falls ja, beschreiben Sie die Strategie(n) bzw. Informationsquellen bitte im Folgenden:

____

____

____

____

2. Sind Ihnen im Laufe der Untersuchung irgendwelche Besonderheiten hinsichtlich des Ablaufs oder des Inhaltes der gezeigten Videos aufgefallen?

O ja O nein

Falls ja, benennen Sie die Besonderheiten bitte im Folgenden:

____

____

____

3. Bitte kreuzen Sie im Folgenden auf einer Skala von 1 (absolut unmotiviert) bis 10 (absolut motiviert) ehrlich an, wie motiviert Sie sich bei der Bearbeitung der einzelnen Experimentteile gefühlt haben.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Teil 1: Ballwechsel 1-96	O	O	O	O	O	O	O	O	O	O
Teil 2: Ballwechsel 97-192	O	O	O	O	O	O	O	O	O	O

4. Hatten Sie den Eindruck, dass in dem Experiment identische Ballwechsel mehrfach gezeigt wurden?

O ja O nein

5. Hatten Sie den Eindruck, dass es innerhalb der Ballwechsel bestimmte Muster oder Regelhaftigkeiten in der Abfolge der Schlagrichtungen gab, anhand derer man den Ausgang eines Schlages erkennen konnte?

O ja O nein

Falls ja, benennen Sie die Muster oder Regelhaftigkeiten bitte im Folgenden:

____

____

____

____

____

Außerdem…

Ich schätze meine Fähigkeit, einen Gegenspieler lange darüber im Unklaren zu lassen, ob ich einen Schlag nach links oder rechts ausführen werde, als … ein.

sehr schwach									*sehr stark*
O	O	O	O	O	O	O	O	O	O

Vielen Dank für Ihre Unterstützung!

ABLAUF DES EXPERIMENTS

- Im folgenden Experiment werden Ihnen Videoclips von Tennisballwechseln aus der Sicht eines Spielers präsentiert. Die Clips stellen jeweils Ausschnitte aus realen Ballwechseln dar und beinhalten insgesamt 4 Schläge des Gegenübers.
- Die Schläge werden aus Ihrer Sicht auf Ihre Vorhandseite (nach rechts) oder Ihre Rückhandseite (nach links) geschlagen (siehe Abbildung unten).
- Jeder Ballwechsel wird bei jedem Schlag ihres Gegenübers im Moment des Schläger-Ball-Kontakts unterbrochen und es erscheint ein schwarzer Bildschirm.
- Damit Sie eine bessere Vorstellung davon erhalten, was Sie im Experiment erwartet, haben Sie die Möglichkeit, vorab einen Gewöhnungsversuch zu absolvieren.
- Nachdem Sie den Gewöhnungsclip durchlaufen haben, startet das Experiment. Das Experiment enthält insgesamt 192 Ballwechsel, die in zwei Blöcken á 96 Ballwechsel präsentiert werden.

AUFGABE

Vorhersage der Schlagrichtung

Bei jedem Schlag Ihres Gegenübers, sagen Sie bitte **so genau und frühzeitig wie möglich** vorher, ob der Ball aus Ihrer Sicht auf Ihre Vorhandseite (nach rechts) oder Ihre Rückhandseite (nach links) geschlagen wird (vgl. gestrichelte Linien in der Abbildung).
Um eine Entscheidung zu treffen, drücken Sie bitte eine der folgenden zwei Antworttasten (vgl. Markierung auf der Tastatur):

Nachdem Sie die Schlagrichtung vorhergesagt haben, erhalten Sie automatisch eine Rückmeldung über den tatsächlichen Ausgang eines Schlages. Die Rückmeldung erhalten Sie, indem der entsprechende Ballwechsel, beginnend mit dem Schläger-Ball-Kontakt Ihres Gegenübers, einfach weiterläuft. Beim nächsten Schläger-Ball-Kontakt Ihres Gegenübers ist dann erneut Ihre Entscheidung gefordert.