Execution and Perception of Effector-Specific Movement Deceptions

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Zusammenfassung

Bewegungstäuschungen spielen in verschiedensten Interaktion im Sport eine besondere Rolle. Das Forschungsinteresse zu diesem Thema hat in den letzten Jahren zunehmend an Bedeutung gewonnen. Dennoch bleiben bislang einige Fragen ungeklärt, insbesondere, welchen kinematischen Besonderheiten Effektor-spezifische Bewegungstäuschungen unterliegen und welche dieser Parameter die perzeptuelle Erkennungsleistung beeinflussen. Noch ist zum Beispiel nicht bekannt, welchen Einfluss raum-zeitliche Unterschiede zwischen den Bewegungen und/oder die Verteilung von Reaktionszeiten auf die Erkennungsleistung haben.

Zur Beantwortung dieser Fragen wurden im Rahmen dieser Arbeit drei Studien durchgeführt. Um die neu gewonnenen Befunde besser in einen Anwendungskontext einzubetten, untersuchte eine erste Studie die Geschwindigkeit interner Verarbeitungsprozesse während domänenspezifischen und unspezifischen RT-Aufgaben. Zudem zeigten die Ergebnisse, dass motorische Expertise zu einer schnelleren Verarbeitung domänenspezifischer Reaktionen beiträgt. Die zweite Studie im Rahmen dieser Dissertation untersuchte die kinematischen Eigenschaften von Effektor-spezifischen Bewegungstäuschungen. Es konnte gezeigt werden, dass die Ausführung Effektor-spezifischer Täuschungen, als eine Art “Bewegungs-Mimikry”, insbesondere eine möglichst präzise Anpassung der räumlichen Parameter an nicht getäuschte Bewegungen erfordert. Eine dritte, psychophysische Studie untersuchte im Folgenden die Rolle von raum-zeitlichen Unterschieden sowie die Verteilung von Reaktionszeiten auf die perzeptuelle Erkennungsleistung getäuschter Bewegungen. Die Resultate zeigten, dass die Erkennungsleistung mit einer Zunahme an raum-zeitlichen Unterschieden linear ansteigt.

Die Ergebnisse der vorliegenden Dissertation tragen erheblich zum tieferen Verständnis der Ausführung und Wahrnehmung von Effektor-spezifischen Bewegungstäuschungen bei. Auf der Seite der Bewegungsausführung konnte gezeigt werden, dass erfahrene Athleten bei der Ausführung von Täuschungen in der Lage sind nicht getäuschte Bewegungen zu imitieren. Dennoch scheint dieser Ansatz immer schwieriger zu werden, je weiter sich die Bewegung der Sichtbarkeit des Handlungseffektes nähert. Auf der Seite des Beobachters wurde deutlich, dass sich

perzeptuelle Diskriminanzleistungen mit dem Anstieg an raum-zeitlichen Unterschieden zwischen den beobachteten Bewegungen verstärkt. Allerdings zeigte sich auch, dass Beobachter häufiger zu Vorhersagefehlern tendierten, wenn frühe Einschätzungen abgegeben wurden. Dies spricht im Gegenzug für die Effektivität der ausgeführten Effektor-spezifischen Bewegungstäuschungen.

Abstract

As a topic that touches on many aspects of movement execution and perception in sports, research on deception has attracted much attention during the last ten years. However, some important questions still remain unresolved—especially what are the kinematic characteristics of more effector-specific movement deceptions that influence an observer's perceptual recognizability? It is still not known how spatiotemporal dissimilarities between movements and/or response time distributions influence this recognizability.

Three different studies were conducted to answer these questions. To embed the new findings into an applied context, a first study investigated the speed of internal processing in domain-specific and unspecific RT tasks. As well as examining speed, results also showed that motor expertise facilitated the processing of domain-specific responses. The second study examined the kinematic characteristics of effector-specific movement deceptions. This showed that expertise in performing those deceptions, as a potential kind of movement mimicry, depends mainly on keeping dissimilarities to non-deceptive movements small. A third, psychophysical study investigated the role of spatiotemporal dissimilarity and response time distribution in the perceptual recognizability of deceptive movements. Results demonstrated that recognizability increases as a function of dissimilarity; however, perceptual performance decreases in the case of early responses.

To sum up, the findings presented in this dissertation contribute to a deeper understanding of how the execution and perception of effector-specific movement deceptions are linked together. On the performer side, they demonstrate that experienced athletes are able to mimic non-deceptive movements while performing effector-specific deceptions. However, this attempt becomes a challenge the closer the execution of the movement phase is to the visibility of the action outcome. On the observer side, they show that the perceptual discriminability between movements increases as a function of spatiotemporal dissimilarity. However, observers more frequently tend to produce a prediction error when giving an early response, thus, indicating the efficiency of the performed effector-specific movement deceptions.

Contents

List of abbreviations

ANOVA	Analysis of variance
CSR	Choice stimulus–response
lArmHand	Left arm and hand
LDA	Linear discriminant analysis
lLegFoot	Left leg and foot
LogL	Log-likelihood
PCA	Principal components analysis
PDF	Probability density function
PPD	Proportion of perceived deceptive trials
PRP	Psychological refractory period
PT	Penalty taker
rArmHand	Right arm and hand
rLegFoot	Right leg and foot
RPT	Response time
RT	Reaction time
RT_1	First reaction time
RT_2	Second reaction time
S–R	Stimulus–response
S1	First stimulus
S2	Second stimulus
SOA	Stimulus onset asynchrony
SSR	Simple stimulus–response

1 Introduction

1.1 Deception

> Reality is easy.
>
> It's deception that's the hard work.
>
> *Lauryn Hill*

1.1.1 What Is Fascinating About Deception

It is truly fascinating to see how human beings are able to intuitively adapt their movement behavior to the changing conditions in our environment. This adaptability is an essential skill for succeeding in various situations in daily life. Interestingly, this ability is observed not only in human beings but also in flora and fauna. Throughout evolution, living creatures and organisms have shown evolutionary adaptations to protect themselves from predators and other environmental hazards. Evidence for this adaptability can still be seen today. The rabbit's zig-zag escape path is just one behavioral example. Through its directional changes, the rabbit attempts to deceive its predator about its previously predicted escape path. Research has demonstrated that a zig-zag path is de facto more successful than a straight path when escaping from a predator (Firestone & Warren, 2010). Other examples are the adaptability of body shape and/or color—one potential kind of mimicry. In this context, the eyed flounder species (Bothus ocellatus), for example, possesses a highly distinctive ability to adapt its body shape and color to its surroundings (Ramachandran & Rogers-Ramachandran, 2008).

Human actors perform a similar form of adaptation or movement mimicry in order to deceive others and gain action advantages. In this context, they attempt to mimic non-deceptive movements in a way that disguises their actual deceptive intent. This potential kind of movement mimicry is utilized in a variety of different human interactions. For example, when thinking on situations in which a performer interacts with an observer, the sport domain offers very good examples for such interactions, particularly when viewing one-on-one situations such as penalty shootouts in association football or team handball. Previous research has demonstrated that distinct perceptual, cognitive, and motor processes are required to act successfully in such moments, and these make both the execution and the perception of deceptive movements very complex tasks (Brault, Bideau, Kulpa, & Craig, 2012; Cañal-Bruland & Schmidt, 2009; Jackson, Warren, & Abernethy, 2006; Lopes, Jacobs, Travieso, & Araújo, 2014; Mori & Shimada, 2013; Sebanz & Shiffrar, 2009). Therefore, research on both the execution and perception of deceptive movements can provide new insights into how these two skills are linked together.

1.1.2 What Are Movement Deceptions?

From faking a pass by gazing in the opposite of the genuine passing direction, over faking the trajectory of a running path by closely followed directional changes, to just disguising the kicking direction of a ball by mimicking a non-deceptive movement—we are permanently confronted with deliberate attempts to deceive when watching sports. When faced with the exceptional skills of expert athletes in anticipating an opponent's action intentions (i.e., the kicking or passing direction), it seems reasonable for their opponents to quite frequently use such movement deceptions. The purpose of these deceptive movements is to compel, first and foremost, an incorrect motor response by an interacting counterpart (e.g., a goalkeeper). This will then induce a competitive advantage by enlarging the target zone. For example, deceiving a goalkeeper into thinking one will throw/kick a ball into the left corner could result in a reaction of the goalkeeper in this direction, and this would increase the open area of the goal in the opposite (right) corner.

All in all, deceptive movements are motor actions that are performed to intentionally mislead an opponent about one's own real action intentions (Kunde, Skirde, & Weigelt, 2011). Such deliberate attempts to disguise genuine action intents are executed in several ways by presenting irrelevant and relevant movement information in different forms.

1.1.3 Different Types of Movement Deceptions

Movement deceptions can be divided roughly into three main categories. First, deceptive movements may be generated by reversing the orientations of the human body. An example is situations in which the head is used to mislead others. So-called “head fakes” are a successful way of deceiving opponents about the passing or shooting direction in a one-on-one situation; the no-look-pass in basketball is exemplary for this category. In this case, the offence player gazes in a direction different to the one in which the ball is passed or shot. The reversed body and head orientation lead to conflicting action predictions. In this type of deception, the irrelevant and relevant movements are performed more or less simultaneously (Kunde et al., 2011).

The same applies for the second type of deception that relies on continuous or discrete whole-body movements. These actions are used, for example, to mislead an opponent when anticipating the running direction of an offence player (e.g., side-step in rugby) or to disguise the shooting direction during a penalty kick in association football.

The third is a type of more effector-specific deception in which the irrelevant and misleading movement precedes the relevant movement; for example, feinting to throw a ball in a 7-m penalty in team handball. In this case, a deceptive movement is followed by a second, but “real” movement—for example, a genuine throw.

Combinations of these deceptive actions are carried out successfully in everyday sports. However, success in performing deceptive movements is determined by their idiosyncratic movement characteristics as well as by the observer’s perceptual skills in recognizing deceptive cues.

1.2 Characteristics of Movement Deceptions

Movements and their idiosyncratic characteristics can be described in different simple ways (e.g., verbal descriptions, series of photographs), but the most powerful and reliable method is to focus on their kinematics. In particular, motion capturing combined with some linear computations can help to describe the movement(s) of the entire human body (cf. Schmidt & Lee, 2011). Basic variables in kinematics are, for example, positional displacement, velocity, or acceleration. However, any variable that describes changes in geometrical configurations over time belongs to the kinematic domain. Taking account of the principles of kinematic specification of dynamics developed by Sverker Runeson in the early 1980s, all attributes involved in determining the movement kinematics belong to the domain of dynamics. Accordingly, not only masses or forces but also intentions and emotions may count as dynamic properties (Runeson & Frykholm, 1983). Consequently, the kinematic analysis of movements provides a reasonably complete picture when characterizing different types of movements and their underlying action intent.

1.2.1 Movement Kinematics

Psychophysical experiments in the last decades have demonstrated the importance of using kinematic information to discriminate between the gender (Barclay, Cutting, & Kozlowski, 1978; Cutting & Kozlowski, 1977) or the emotional states (Dittrich, Troscianko, Lea, & Morgan, 1996) of an agent as well as identifying different types of actions (Abernethy & Russel, 1987a; Dittrich, 1993; Runeson & Frykholm, 1981). The same holds for discriminating deceptive from non-deceptive movements (Jackson et al., 2006; Runeson & Frykholm, 1983; Sebanz & Shiffrar, 2009). Both disguising genuine action intentions (performing deceptions) and detecting intentions of deceit (perceiving deceptions) rest on the same assumption: Hidden cognitive states (intentions) that a performer would like to remain hidden become more or less observable in the movement kinematics of the deceptive actions being performed.

During the last decade, research in the sport science domain has delivered a broad body of literature on the ability of experienced athletes to effectively recognize deceptive action intentions (see Mori & Shimada, 2013, for an overview). However, little is known about the kinematic features of the deceptive movements performed. In this context, a number of studies have concentrated on the analysis of discrete (Lopes et al., 2014; Smeeton & Williams, 2012) or continuous (Brault, Bideau, Craig, & Kulpa, 2010) whole-body deceptions. In general, they have demonstrated that genuine and deceptive movements typically display a degree of spatial and/or temporal difference in terms of their motion trajectories and temporal dynamics.

The Role of Exaggerating and Minimizing Kinematic Cues

Up to now, it has been consistently reported that the exaggeration of specific kinematic features is one major characteristic of movement deceptions. As an example, Brault et al. (2010) reported that the most significant differences in movement kinematics between deceptive and non-deceptive movements were found in upper trunk movements, whereas kinematics of the lower trunk were minimized in order to maintain postural stability. It can be concluded that effective deceptions of whole-body movements (i.e., side-step in rugby) include deceiving an opponent by exaggerating the kinematic parameters providing false information while minimizing genuine information linked to body reorientation in order to disguise the actual intent. However, it is also necessary not to over-exaggerate or over-minimize the kinematic pattern, because this could result in an overall artificial movement pattern (Brault et al., 2010; Lopes et al., 2014) and thereby facilitate recognizability of the deceptive intent. In other words, an athlete should attempt to reproduce some of the non-deceptive movement characteristics while performing whole-body movement deceptions.

The Non-Substitutability of Genuine Actions

Another feature while performing deceptive movements is described as the non-substitutability of genuine actions (Richardson & Johnston, 2005). As already mentioned, despite sophisticated attempts to disguise deceptive action intentions, human observers are sensitive to deception (Jackson et al., 2006; Runeson & Frykholm, 1983; Sebanz & Shiffrar, 2009). Under certain circumstances, the inability to deceive suggests differences between the kinematic patterns associated with the deceptive versus non-deceptive (genuine) movements, and also that observers are sensitive to such disparities. The difference in the kinematic patterns can be explained by the non-substitutability of genuine actions. The different movement characteristics or dispositions of an individual specified by the kinematic movement pattern are multidimensional and nonlinear (Runeson & Frykholm, 1986). The effects resulting from the change of one kinematic factor cannot be replaced, or cancelled out by changing another factor. When trying to create a deceptive movement pattern, one may be able to produce some of the kinematic details of the corresponding non-deceptive movement, but not all of the necessary details needed to convince an observer that the movement is genuine (Richardson & Johnston, 2005). Suppose, for example, that in association football, goalkeepers make use of the orientation of the non-kicking foot when anticipating a penalty kick (Franks & Hanvey, 1997; Savelsbergh, van der Kamp, Williams, & Ward, 2005). Because of this knowledge, penalty takers may try to disguise their action intentions by kicking the ball in the opposite direction to that toward which the non-kicking foot is oriented. However, some properties of the kicking action need to be established in order to kicking the ball into the intended direction. This means that some of the distributed kinematic variables will probably remain specific to the particular kicking direction of the penalty taker (Lopes et al., 2014). Indeed, it has been reported that differences in deceptive and non-deceptive movement patterns become more obvious the closer the execution of the action is to the visibility of the action outcome (Brault et al., 2010; Lopes et al., 2014). One possible reason for the non-substitutability of genuine actions could be some differences between the deceptive and non-deceptive movements in their biomechanical regularities and/or constraints (Brault et al., 2010). For example, in throwing, high action forces are required in non-deceptive movements in order to transfer the kinetic energy to the ball, whereas high forces must be avoided in deceptive throwing in order to maintain postural stability.

To sum up, deceptive movements are subject to some idiosyncratic kinematic features as well as some more general characteristics that might be due to fundamental (biomechanical) constraints when performing deceptions in general. However, up to now, it is unclear which kinematic features describe the nature of more effector-specific deceptions, for example, throwing a ball.

1.2.2 Deliberate Effects on Perception

Picking-up advance kinematic information is a generic and determining factor for the success of anticipating action effects in sport (Dicks, Button, & Davids, 2010a, 2010b; McMorris & Colenso, 1996). One major goal in making use of movement deceptions to acquire a competitive advantage involves manipulating movement kinematics in order to aggravate the process of information pick-up and anticipation. The kinematic manipulation of body-based information involves eliciting some deliberate effects on an observer's perceptual processes (Brault et al., 2010).

The above-mentioned principle of the kinematic specification of dynamics (Runeson, 1977; Runeson & Frykholm, 1983) reveals that the characteristics and the richness of the kinematic patterns of a movement specify the underlying intentions of an action. Hence, it is conceivable that manipulating a kinematic pattern (i.e., when performing a deceptive movement) will result in a modulation of the informative movement dynamics (i.e., action intentions). This could facilitate the perception of non-deceptive movements, for example, through, the holistic exaggeration of the kinematics (Pollick, Fidopiastis, & Braden, 2001). However, it can be also considered to enhance misperception by an observer when trying to exaggerate individual kinematic cues while performing a deceptive movement. This manipulation will probably be most effective when the relevant cues that facilitate anticipation are manipulated or provide misleading information (Brault et al., 2010, 2012; Jackson et al., 2006). Extracting sufficient information for the anticipation then becomes a challenge. However, it is still not known how far the different manifestations of delivering misleading information influence the perceptual recognizability of deceptive movements.

Assumptions regarding the perceptual-cognitive processing of deceptive whole-body movements suggest that exaggeration in movement is thought to change the observer's perceptual mode of functioning (Jackson et al., 2006; Smeeton & Williams, 2012). In order to explain how deceptive movements are misperceived, it is proposed that the exaggeration of kinematic cues changes the mode of functioning from an invariant (direct) to a cue-based (heuristic) mode. Quite intuitively, movements containing exaggerated or salient misleading information should provoke cue-based judgments (Jackson et al., 2006) and result in a decrease of perceptual recognizability.

This, in turn, suggests evidence for the success of the performed deceptive movement. An alternative view is that it is the modification of advanced local cues during deception, rather than movement exaggeration, that may be responsible for the perceptual mode of functioning. Under this assumption, first advanced cues would indicate a misleading action before switching to the characteristics of the intended movement (Jackson et al., 2006; Smeeton & Williams, 2012). Nevertheless, it is still not known how far the non-substitutability of genuine actions negatively affects this attempt.

1.3 Perception of Movement Deceptions

Anticipating the future outcome of an observed action is an important skill for coping with the challenges of daily life, and particularly for coping with different situations in competitive sport. Because most sports, and especially team ball games, require athletes to process information under temporal constraints, the use of different informational sources for the action recognition and effect anticipation is a fundamental skill for adapting to the unique constraints of the task (Williams, Ford, Eccles, & Ward., 2011). In light of the fact that in many sports, and particularly in fast ball games such as tennis or baseball, the ball flight duration from one opponent to the other is usually shorter than the combined sum of reaction and movement time (Williams et al., 2011), it has been suggested that athletes must anticipate the future action outcome significantly before the outcome itself becomes visible. This ability then provides athletes more time to initiate and execute an appropriate motor response.

1.3.1 Informational Sources

Making assumptions about the action intentions of an opponent’s movement based on its kinematics is one major source of information with which to anticipate future action outcomes. Several techniques have been used to study the nature of the different strategies of kinematic information pick-up that can help to facilitate anticipatory performance. Other reported non-kinematic sources of information for anticipation are described by the general term of contextual information. This, for example, includes information about situational probabilities, exposure to an opponent's action preferences, or the sequences of previous action outcomes (Cañal-Bruland & Mann, 2015). The following pages will review current knowledge on the different information sources in detail.

Movement Kinematics

Action recognition and effect anticipation have been a topic in psychological research for many decades. Inspired by the pioneering work on point-light displays by Johansson (1973), a broad body of literature has highlighted the importance of kinematic information when making perceptual judgments not only in daily life (Dittrich, 1993; Runeson & Frykholm, 1981; Loula, Prasad, Harber, & Shiffrar, 2005) but also in many competitive sport situations (see Williams, Ford, Eccles, Ward, 2011, for a detailed overview). The benefits of the point-light technique are that it provides purely kinematic information. Although, under certain conditions, the technique includes some limitations in terms of providing ambiguous information about motion in depth (Vanrie, Dekeyser, & Verfaillie, 2004; Weech, McAdam, Kenny, & Troje, 2014), in most cases it simply displays a complete picture of the underlying movement kinematics of the represented motion.

Likewise, the simple use of videotaped motion has also provided significant evidence for the importance of using kinematic cues when making perceptual judgments in sports (Abernethy & Russel, 1987a; Mori, Ohtani, & Imanaka, 2002; Williams & Davids, 1998). However, this is now an outdated technique for investigating the kinematic cues used in the context of action recognition and effect anticipation. Recent years have seen a dramatic increase in the number of experiments using 3D motion stimuli (Brault et al., 2012; Craig, 2014; Vignais, Kulpa, Brault, Presse, & Bideau, 2015). This technique makes it possible to visualize simplistic 3D motion avatars that also provide purely kinematic information without other superficial cues (e.g., clothing or environmental conditions). And, due to its 3D nature, the technique also makes it possible to visualize distinct information about motion in depth.

More than two decades ago, Runeson and Frykholm (1983) first reported the influence of kinematic changes on the perceptual judgment of deceptive versus non-deceptive actions. In one of their experiments, the authors investigated the perceptual sensitivity for more object-directed deceptions. At the performer site, participants were instructed to disguise the weights of lifted boxes. At the observer site, participants were instructed to judge the weights of the lifted boxes based on the observable movement kinematics. Results demonstrated that observers were highly sensitive to deception as a function of weight. The authors concluded that the actor's attempt to deceive the observer about the lifted weight had only little if any of its intended effect.

In the last few years, research in the sport science domain has provided much evidence on athletes' sensitivity to deceptive action intentions based on the observable movement kinematics (Cañal-Bruland & Schmidt, 2009; Cañal-Bruland, van der Kamp, & van Kesteren, 2010; Jackson et al., 2006; Mori & Shimada, 2013; Rowe, Horswill, Kronvall-Parkinson, Poulter, & McKenna, 2009; Sebanz & Shiffrar, 2009). As an example, Jackson et al. (2006) investigated the effects of whole-body movement deceptions (side-steps) on anticipatory performance in rugby. To avoid being tackled, offence players perform side-steps in the opposite direction to that in which they will finally run. Using videotaped sequences of these actions, participants were asked to judge whether the observed player would change direction to the left or to the right. Results showed that the athlete's recognizability did not significantly differ between the deceptive and non-deceptive intent. This indicates that athletes are extremely sensitive to the intentions underlying whole-body movement deceptions. Other studies have confirmed this sensitivity to deception. However, this sensitivity in these studies was in general decreased in comparison to the sensitivity to non-deceptive intentions (Dicks et al., 2010a; Mori & Shimada, 2013; Grèzes, Frith, & Passingham, 2004; Rowe et al., 2009).

Moreover, research on action recognition investigating the influence of kinematic changes in the context of temporally and/or spatially over-exaggerated non-deceptive movements (Hill & Pollick, 2000; Pollick et al., 2001) indicates that the recognizability of observed movements depends on the amount and sufficiency of available kinematic information. However, up to now, the question whether or not differences in the kinematic pattern of deceptive movements influence the perceptual recognizability of these movements as well is still unanswered.

Principles of information pick-up. Up to now, what are the underlying perceptual strategies in the context of deceptive action recognition or anticipation is still an open question. Inherently, the principles of information pick-up reported for the anticipation of non-deceptive action outcomes should also be applicable in the context of recognizing deceptive action intents. Yet, it has been reported that athletes make use of qualitatively different visual search strategies when extracting environmental information in different sport tasks. However, evidence on the importance of extracting kinematic information from distal body regions—in particular, the end effector and its surrounding areas—has been shown consistently for different tasks (Abernethy, 1990; Savelsbergh, Williams, van der Kamp, & Ward, 2002; Ward, Williams, & Bennett, 2002). Quite intuitively, these regions are assumed to contain specific effector attributions and salient information for the observer that distinguishes them from other regions. Nonetheless, this does not exclude the importance of other body parts per se. Because it has been shown that it is the pick-up of relative motion between specific body regions rather than the extraction of isolated cues that facilitates anticipatory behavior, it appears that effective anticipation relies on a more broadly distributed (global) rather than isolated (local) strategy of information pick-up (Williams et al., 2011).

Expert anticipation. As mentioned above, research has provided evidence for a decrease in the perceptual recognizability of deceptive in comparison to non-deceptive movements. In order to describe the underlying mechanisms of changes in the observer’s sensitivity to deception, it would be useful to focus on several findings reported in the context of research on expert anticipation. In general, it can be observed that (highly) experienced athletes outperform novices in anticipating the intentions or future outcomes of an observed action (see Mann & Savelsbergh, 2015, for an overview). In the expertise literature, this advantage is explained by the use of different strategies in information pick-up. It is suggested that expert athletes make use of a more broadly distributed rather than isolated information pick-up, whereas novices rely mainly on information attributed to isolated cues. As a consequence, the perceptual strategies utilized by experts involve a degree of flexibility in making use of different kinematic information. A more global perceptual strategy is considered to make athletes less susceptible to the attempts of an opponent to disguise genuine action intentions (Williams et al., 2011). In fact, findings indicate that inexperienced athletes are more susceptible to deception than their experienced counterparts (Cañal-Bruland & Schmidt, 2009; Dicks et al., 2010a; Rowe et al., 2009; Sebanz & Shiffrar, 2009). However, a different line of reasoning for this effect is given by Jackson et al. (2006) who suggested that the nature of deceptive movements (e.g., exaggeration of isolated cues) also changes the observer's perceptual mode of functioning from an invariant (holistic) to a more cue-based (inferential) mode. This is considered to result in an overestimation of confidence in a judgment relative to its accuracy, thereby implying a decrease in perceptual recognizability for deceptive movements (Jackson et al., 2006; Smeeton & Williams, 2012). Further, this assumption could also explain the slight, but significant decrease in an expert's perceptual recognizability of deceptive in comparison to non-deceptive movements.

A subsequent explanation for the expertise advantage is taken from theories of action simulation (Jeannerod, 2001; Zentgraf, Munzert, Bischoff, & Newman-Norlund, 2011) and internal modeling for the effect anticipation (Blakemoore & Decety, 2001; Shmuelof & Zohary, 2007). Making assumptions about the action intentions of an opponent's movement based on one's own motor experiences allows us to cope with the uncertainties of the visual input and to organize it in a predictive manner. In this context, it is argued that action observation activates internal representations of the observer's motor system that let the observer simulate the movement behavior internally (Jeannerod, 2001; Zentgraf et al., 2011), and consequently infer the action goal and also predict the action intent by means of predictive forward modeling (Blakemoore & Decety, 2001; Shmuelof & Zohary, 2007). This process is thought to be facilitated by an acquired "storage" of internal (motor) representations resulting from many years of motor practice (Zentgraf et al., 2011).

Contextual Information

Different informational sources are used in the context of anticipation in sport. As described above, one important source of information is provided by the observable movement kinematics. Another source of information relies on more contextual information including non-kinematic cues (i.e., situational probabilities or action preferences) that are also thought to influence the anticipatory performance of an observer (see Cañal-Bruland & Mann, 2015, for a detailed overview) and perhaps be useful in the context of ambiguous kinematic information. Except for a handful of studies in the late 1970s (cf. Alain & Proteau, 1980; Girardin & Alain, 1978), it is only quite recently that this field of research has attracted further attention. Beginning with the investigations of Abernethy, Gill, Parks, and Packer (2001), it has been demonstrated that, for example, situational probabilities can be used to anticipate future action outcomes without any other kinematic information on the opponent's movement. Researchers then started to investigate the use of other non-kinematic information more systematically in the context of action anticipation. This included the influence of probabilistic information such as an opponent's court position and its relation to future action outcomes (Farrow, Whiteside, & Reid, 2016), exposure to an individual's action preference (Mann, Schaefers, & Cañal-Bruland, 2014; Navia, van der Kamp, & Ruiz, 2013), or exposure to previous sequences of outcomes (Loffing, Stern, & Hagemann, 2015).

Furthermore, research has demonstrated that the anticipatory performance of experienced athletes may be influenced by the implicit or explicit knowledge about situational events in the past or through a cost–benefit trade-off for responding or not responding (Cañal-Bruland & Schmidt, 2009). Also, research on simple heuristics suggests that athletes are prone to make use of various informational sources for fast judgments in the presence of uncertainty (De Oliveira, Lobinger, & Raab, 2014; Raab, 2012).

1.3.2 Information Processing and the Role of Psychological Refractoriness for Deception

Not only the use of effective perceptual strategies for sufficient information pick-up but also the processing of perceived information is a determining factor in the process of successful anticipation. This is particularly relevant if processing includes the preparation and initiation of an appropriate motor response (e.g., reaction of a goalkeeper to the opponent's intent to throw a ball). The time taken to initiate a response can indicate the speed of internal processing. In general, research on reaction time (RT) has shown that practice might facilitate the speed of internal processing (Mowbray & Rhoades, 1959; Rabbitt & Banerji, 1989). However, up to now, expertise research has concentrated on arguing that superior processing performance is driven by an advantage gained from experts having better trained anticipatory skills than novices (see Mueller & Abernethy, 2012; Williams et al., 2011, for overviews). Another important principle of information processing comes to mind when thinking about the attempt to deceive another. In such situations, athletes (i.e., goalkeepers or defense players) often have to reprogram their reactions in order to not allow their opponents to deceive. This is why opponents try to make use of the principles referred to as the so-called psychological refractory period (PRP). Effects of the PRP are investigated using double stimulation paradigms in which participants must respond in close succession to two stimulations that require different responses (Telford, 1931). As replicated in many experiments, the processing of the second stimulation (e.g., the non-deceptive movement) becomes affected by the ongoing processing of the first stimulation (e.g., the deceptive movement). Because in many sports, and particularly in fast ball games, time to react is limited, athletes try to make use of the PRP principle in order to successfully deceive another. In this context, a basic principle of deceit is that genuine movements should follow deceptive ones after a sufficient time gap (longer than 50 ms), so that both movements will be processed separately rather than grouped together. Also, onset asynchrony between both movements should not be so long that the effects of refractoriness fade out (no longer than 250 ms). Yet, little is known about adaptations of the PRP effect as a result of training or skill acquisition (cf. Schmidt & Lee, 2011). It has simply been demonstrated that high levels of task practice facilitate the processing of the second stimulation (Gottsdanker & Stelmach, 1971; Van Selst, Ruthruff, & Johnston, 1999).

1.4 Outline

Although movement deception is a significant topic in research on action recognition and anticipation in the sport science domain, many interesting questions still remain unanswered. Regarding the execution of deceptive movements, the literature shows that performing deceptions underlies some specific characteristics that are assumed to influence recognition performance in the observer. Up to now, knowledge is based mainly on findings taken from the kinematic analysis of whole-body deceptions. In addition, little is known about the attributes of expertise in performing (effector-specific) movement deceptions.

Regarding the perception of deceptive movements, much is known about the use of kinematic cues to anticipate the deceptive action intent of an opponent. Yet, it remains unclear whether changes in the spatial and temporal characteristics of the movement kinematics impact on the perceptual recognizability of deceptive movements. Further, the literature demonstrates that experienced athletes are better and faster than novices in recognizing (deceptive) action intent. It is well investigated that this superior recognizability is a result of differences in perceptual strategies. However, up to now, it has been assumed that the differences in processing speed are driven by a better trained anticipatory behavior.

Three experiments were conducted to answer these questions. They should help to contribute to a deeper understanding of how the execution and the perception of movement deceptions are linked together. In all experiments, I tried to elaborate experimental paradigms that included the use of highly domain-specific tasks while ensuring optimal experimental control.

The first study addressed the question whether the speed of internal processing is dependent on or independent from domain-specific motor expertise in unpredictable stimulus–response tasks as well as in a double stimulus–response paradigm. The latter would best model the processing demands in responding (reacting) to deceptive actions. A broad body of literature reports no differences between the processing speed of expert and novice athletes. Nonetheless, Rabbitt and Banerji (1989) demonstrated in a RT paradigm that high amounts of training facilitate the speed of processing. Therefore, I conducted a behavioral experiment in which participants were asked to respond as quickly as possible to different stimuli in domain-specific or domain-unspecific RT tasks without any chance of anticipating the occurrence of stimulus onset. In addition, I anticipated that these findings would also help to better link together the perceptual and action processes in the context of human movement interactions.

The second study looked at the characteristics of performing deceptive movements. Both Brault et al. (2012) and Lopes et al. (2014) showed that exaggerating misleading and minimizing genuine information are major features when performing whole-body movement deceptions. In this type of deception, the irrelevant and relevant movements are performed more or less simultaneously. However, the effectiveness of deceptive movements in the Lopes et al. (2014) study was also limited by the non-substitutability of genuine actions. Here, a further experiment was conducted to tackle the question about the kinematic characteristics of more effector-specific movement deceptions—a potential kind of movement mimicry.

The first two studies provided an important background against which to complete the picture of research on movement deceptions with a third, psychophysical experiment. This perceptual study dealt with the question how differences in the spatial and temporal movement patterns of deceptive versus non-deceptive movements influence perceptual discriminability. Because most research on action recognition or anticipation used tasks without any temporal constraints, this study also tackled the question of the role of response time distributions in perceptual judgment.

2 Internal Perceptual-Motor Processing during Domain-Specific and Unspecific Simple and Double Stimulus-Response Tasks

A similar version of this chapter has been published as:

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Processing information is a fundamental cognitive activity, especially the linking together of perceptual and action processes. In this context, expertise research in the sport domain has concentrated on arguing that superior processing is driven by an advantage to be found in anticipatory processes. This has resulted in less attention being paid to the benefits coming from basic internal perceptual-motor processing. Against this background, the present study examined whether the speed of internal processing is dependent on or independent from domain-specific motor expertise in unpredictable stimulus–response tasks and in a double stimulus–response paradigm. Thirty male participants (15 team handball goalkeepers and 15 novices) performed domain-unspecific simple or choice stimulus–response (CSR) tasks as well as CSR tasks that were domain-specific only for goalkeepers. As expected, results showed significantly faster RTs for goalkeepers on domain-specific tasks, whereas novices' RTs were more frequently excessively long. Further, overall differences between groups in the double stimulus-response paradigm were also significant. It is concluded that the reported expertise advantage might be due to recalling stored perceptual-motor representations for the domain-specific tasks, implying that experience with (practice of) a motor task explicitly enhances the internal processing of other related domain-specific tasks.

2.1 Introduction

Motor actions in sports often rely on the fast reactions needed to successfully perform basic tasks such as starting a 100-meter race or defending a goal from an opponent's attack. Two different mechanisms seem to be fundamental for what are often incredibly fast reactions. The first is basic RT as evidence for fast internal processing. This might be shorter for skilled compared to unskilled athletes. RT has been a key topic in psychological research for more than 150 years (Helmholtz, 1850; Donders, 1869/1969; see Sanders, 1998, for an overview). RT is commonly defined as a measure of time elapsing between the occurrence of a stimulus and the onset of the response to it. In the early days, Helmholtz (1850) measured RT in order to deduce the speed of peripheral conductivity, but along with Donders (1869/1969), he noticed that RT is more likely to be the time required for internal processing (see Sanders, 1998). Thus, the time taken to initiate a response can indicate the speed of this internal processing. Regarding the second mechanism, specifically for fast ball games, quick reactions may often be grounded in the advantage gained from experts having better trained anticipatory processes than novices. Anticipation implies that athletes recognize critical movement features in their opponents at an earlier stage that allow them to possibly predict an action outcome before the outcome itself has been realized (Williams, Ward, Knowles, & Smeeton, 2002; Balser et al., 2014; Bischoff et al., 2014). This could be a reason for shorter RTs. However, the advantage of anticipatory processes does not just produce quick reactions. Such processes also offer more time to initiate a response, because the critical movement features of an opponent are recognized more precisely and at an earlier stage (Abernethy & Russell, 1987a; Savelsbergh et al., 2005; Williams et al., 2011). Hence, both basic internal processing and anticipatory processes can produce quicker responses. However, they rely on distinctly different internal perceptual-motor processes.

In recent years, expertise research in the sport domain has focused mainly on the advantage of the anticipatory processes underlying superior expertise performance (Starkes, 1987; Helsen & Starkes, 1999; Williams, Davids, & Williams, 1999; Williams et al., 2002; Savelsbergh et al., 2005). Although a few studies have used additional RT measurements to examine differences between skilled athletes and novices (Spirduso & Clifford, 1978; Starkes, 1987; Travassos et al., 2013), their results have been inconsistent and they did not exclude anticipatory processing in their experimental tasks such as the different results are hardly comparable. The same mixed pattern has also been demonstrated in comparisons between physically active and non-active people (Spirduso, 1980; Yandell & Spirduso, 1981; Nougier, Azemar, & Stein, 1992; O'Donovan, Cheung, Catley, McGregor, & Strutton, 2006). Hence, despite a comprehensive body of evidence on basic internal processing (Schmidt & Lee, 2011, for a review), less attention has been paid to the effects resulting from motor expertise in certain S–R contingencies. It should be noted that possible effects resulting from motor expertise cannot be treated separately in such S–R tasks, but tend to be combined in the sense of perceptual-motor processes. In this context, one could argue, for instance, that the quicker responses of athletes are not a general RT phenomenon (i.e., selection process), but more a result of their expertise in performing domain-specific and integrated responses (i.e., training process). According to Farrow and Abernethy (2002) and Williams et al. (2011), this expertise relies essentially on improved anticipatory perceptual components. Expertise research generally proposes that expertise effects are a result of extensive training and do not transfer to other skill domains. This notion is similar to the concept of training and transfer specificity (Thorndike & Woodworth, 1901; Magill, 2007). It predicts that motor training produces specific effects that hardly transfer to other motor skills. This issue has been demonstrated for postural control (Robertson & Elliott, 1996; Naumann, Kindermann, Joch, Munzert, & Reiser 2015) and for skill-relevant contextual effects (Proteau, 1992). This is in line with trainings of specific S–R contingencies for experts that rely mainly on anticipatory perceptual components (Farrow & Abernethy, 2002; Williams et al., 2011). However, any test of the effects of motor expertise on internal processing speed in an S–R task has to ensure that anticipatory perceptual processes are excluded.

Another important issue regarding internal perceptual-motor processing comes to mind when thinking about situations in which athletes have to reprogram their reactions because, for example, an opponent has performed a deceptive action. In principle, this phenomenon can be viewed as a double stimulus–response task as found in research on the PRP (Telford, 1931; Pashler, 1984; cf. Schmidt & Lee, 2011). PRP tasks contain specific S–R contingencies that may help to elucidate performance differences between various skill levels. These experimental paradigms present a close succession of two stimuli that both require a motor response. Researchers have shown that high levels of practice on these tasks reduce the dual-task costs (Gottsdanker & Stelmach, 1971; Van Selst et al., 1999). For instance, Van Selst et al. (1999) showed that the PRP effect in a speeded S–R task requiring a motor response dramatically decreased by almost 90% of the initial effect after 7 weeks of practice.

Against this background, the present study investigates the effects of motor expertise on the speed of internal perceptual-motor processing of unpredictable S–R tasks in a specific sport setting. Specifically, we ask whether simple or choice RTs are independent from or dependent on specific motor expertise—an expertise that is associated with the history of individual (training) experiences. This is a critical point for expertise research in the sport domain, because the typical expertise advantage is interpreted restrictively as anticipatory perceptual processing and not as a potentially basic internal processing (RT) advantage. Additionally, we ask whether experienced athletes (team handball goalkeepers), who can be considered to be experts in dealing with deceptive behavior, will show superior performance on a double stimulus-response task in which they have to reprogram their action. The main objectives of the present study were as follows: first, we used unpredictable simple and choice S–R tasks to study effects of motor expertise on basic internal perceptual-motor processing. This is why we examined two groups with different expertise: experienced semi to successful elite team handball goalkeepers (as classified by Swann, Moran, & Piggott, 2015) who are considered as *experts* for domain-specific responses in the form of hand or foot movements in response to a stimulus, and *novices* with no background in goalkeeping. Second, we investigated the effects of motor expertise in a double stimulus–response task that required expertise-specific motor responses, but also excluded anticipatory perceptual processes by using unpredictable stimulus onsets.

We applied a design containing a total of five experimental conditions. Participants had to use movements to react as quickly as possible to different stimuli in four basic conditions with different S–R alternatives. Participants were naïve to all stimuli used during the experiment. Movements to be made were either familiar only to the experts or they were unfamiliar to both groups. This resulted in two expertise-specific and two expertise-unspecific conditions. Specific conditions required a handball-related motor response, whereas the unspecific conditions required finger movements only.

In a fifth condition, we adjusted the typical PRP paradigm to present a double stimulus–response task similar to a goalkeeper's reaction to being deceived by an opponent. The respective responses were familiar only to the expert group. In all S–R tasks, participants could not have anticipated either the event of stimulus onset or the required motor response. We predicted that we would observe shorter RTs among the experts in comparison to the novices on those basic S–R tasks that were expertise-specific, but no differences in RTs on expertise-unspecific basic S–R tasks. This hypothesis was derived from conceptions of training and transfer specificity. For the double stimulus–response paradigm, we predicted that experts would show a significantly smaller increase in RTs for the second response than novices.

2.2 Methods

Participants and Design

Thirty-three male participants with normal or corrected-to-normal vision volunteered for this study (M_{age} = 24.4 years, SD = 4.9). The study was approved by the local ethics committee of the Justus-Liebig-University Giessen and all participants gave their informed written consent in accordance with the Declaration of Helsinki. Participants were divided into two groups: experts (semi to successful elite team handball goalkeepers, according to Swann et al., 2015, n = 15) and novices with experience in recreational sports, but no experience in team handball or goalkeeping (n = 18). Novices reported on average to exercise weekly in different sports such as (table) tennis, badminton or fitness. Team handball goalkeepers from the expert group reported practicing for an average of 8.7 hrs per week (SD = 2.5) and they had a mean playing experience of 14.3 years (SD = 4.4). Three participants of the novice group had to be excluded from the data analysis because they reported having an earlier history of club level experience in team handball.

In summary, we conducted an experiment with five different sessions of unpredictable S–R tasks. These tasks were designed so that participants could not anticipate either the event of stimulus onset or the required motor response in order to ensure that anticipatory perceptual processes were excluded. Stimuli figuration (symbolic pictures of a ball) in all conditions was considered to be unspecific for both the novices and the expertise domain. The responses to be made on these tasks were either a movement that was familiar only for the experts (expertise-specific) or a movement that was unfamiliar (expertise-unspecific) for both groups. A detailed description of the different experimental conditions is given below.

Unspecific simple stimulus–response (SSR) task. Participants had to release a button that they were pressing with their right or left index finger (*10 times each*) as soon as a stimulus appeared in the middle of a screen.

Unspecific two-choice stimulus–response (2CSR) task. Participants had to release one of two buttons being pressed by their right and left index finger as soon as a stimulus appeared in the corresponding right or left half of the screen (*20 times each*).

Specific two-choice stimulus–response (2CSR) task. Participants had to move either the left or right hand from a starting position to a target placed in the left or right upper corner of a handball goal (*20 times each*). Stimuli were the same as in the unspecific 2CSR task.

Specific four-choice stimulus–response (4CSR) task. Participants had to move either the left or right hand from a starting position to the same targets as in the specific 2CSR task or bring together their left or right hand and foot at a specified target location in the lower left or right corner of the goal (*20 times each*). Stimuli on screen appeared in one of four quadrants.

Specific double stimulus-response (double SR) task. Participants had to react to two closely spaced stimuli (SOA: 156 ms) by moving their left followed by their right (or their right followed by their left hand) from the starting position toward the targets in the upper left or upper right corner of the handball goal (*20 times each*). They were instructed to discontinue their first response as soon as the first stimulus (S1) disappeared and the second (S2) appeared on the screen. Reaction times for the first responses are labeled double SR RT_1, and those for the second responses are labeled double SR RT_2. This task contained a total of 130 trials, with *40 trials* of the double SR task being embedded in a pseudo-randomized order among 90 trials of specific two-choice reactions (double SR 2CR) in which only S1 was presented.

Visualizations of the stimuli for all conditions together with their detailed characteristics are presented in Figure 1. The specific S–R tasks were considered to simulate the defensive reactions of a team handball goalkeeper and were therefore assumed to be expertise-specific to the expert group alone, whereas the unspecific tasks were expertise-unspecific for both groups. In the unspecific S–R conditions, we deliberately chose button-release tasks to compare these unspecific with the specific sports-related movement tasks. For many years, such button-press/release tasks served as a typical response type in action prediction research in sports until researchers in that domain suggested designing experiments in which participants are required to give highly domain-specific responses (Farrow & Abernethy, 2003; Mann, Abernethy, & Farrow, 2010).

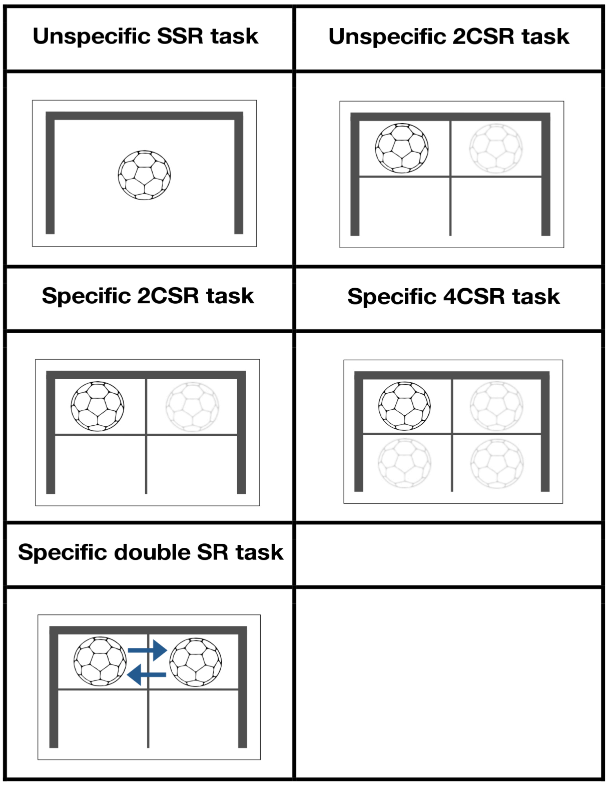

Figure 1 **|** *Stimuli. Characteristics of all experimental conditions.*

Procedure

Prior to the experimental block, participants attended a short test and introductory session to familiarize themselves with the experimental setting. For the experimental session, a set of six retroreflective markers was attached to their fingers, hands, and shoes. Markers were fixed directly to the skin. During the experiment, participants stood in the middle of a handball goal in front of a small desk with a response time box placed in front of them. The screen presenting the visual stimuli (37.7 cm in the horizontal and 30.3 cm in the vertical plane) was placed 1.5 m in front of them and adjusted to each participant's height. The specific and unspecific conditions were presented in blocks in two different sessions in a pseudo-randomized order. Participants received a short explanation of the task in each condition and were instructed as follows: *react as quickly and accurately as possible to the corresponding stimulus and hit the targets in the specific S–R tasks*. All trials in each condition started with a fixation cross. This was displayed on the screen for a duration of 1.5–2.5 s before the stimulus of the corresponding task appeared. The respective time jitter was necessary to exclude anticipatory behavior by making it impossible for participants to predict the occurrence of the presented stimuli. Visual stimuli were generated at a resolution of 1280 × 1024 pixels with Presentation software (Neurobehavioral Systems, Albany, NY, USA) running on a control PC. Stimuli were presented for a duration of 3.5 s on screen in order to provide enough time for retaking the initial position after reacting to a stimulus. The timing of the stimuli for all conditions is illustrated in Figure 2.

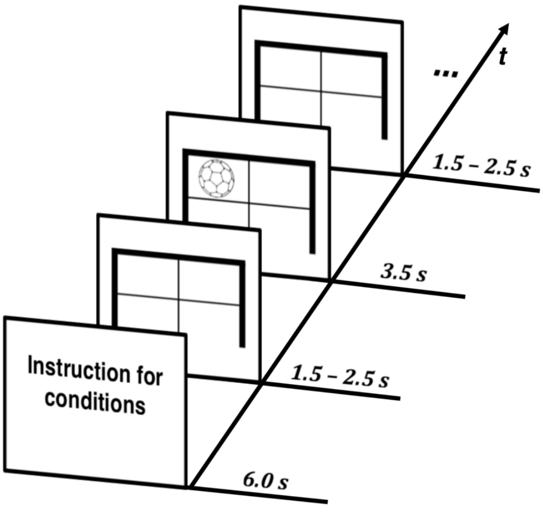

Figure 2 | *Temporal structure: Timing of stimuli for all conditions.*

Data Collection

Movement data were collected using a motion capture system (VICON, Oxford, England) equipped with 13 CCD high speed cameras and remote-controlled by the Presentation software. The system tracked three-dimensional trajectories of the retroreflective markers with a spatial accuracy of 1 mm and a temporal resolution of 240 Hz. The accuracy of RTs, calculated from the motion data, was controlled with a response time box (V5.1, LOBES, The Ohio State University, Columbus, OH, USA) guided through PsychToolbox-3 in MATLAB R2014a (MathWorks, Natick, MA, USA). The motion capture system recorded trigger signals (stimulus presentation on the screen) simultaneously with the motion data.

Data Analysis

Motion capture data were preprocessed with Nexus 1.7 (VICON, Oxford, England). RTs in all conditions were calculated in MATLAB R2014a (MathWorks, Natick, MA, USA) as the time between stimulus and movement onset based on the velocity profiles of the markers. When calculating RTs, we took the visual delay (28 ms) when presenting the stimuli on the computer screen into account. The accuracy of motion-based RTs in the unspecific S–R tasks was controlled through the RTs measured by the response time box. Subsequently, we inspected RTs visually and used absolute cutoffs for data correction adjusted to our experimental design (as recommended by Ramsay & Silverman, 2002, and Whelan, 2008). Additionally, we took traditional findings on RT in terms of the available number of S–R alternatives into account (cf. Schmidt & Lee, 2011). In the specific and unspecific SSR and 2CSR tasks, we discarded trials outside the interval 120 ms < RT < 450 ms (4.0%). In the specific 4CSR task, we discarded trials outside the interval 220 ms < RT < 550 ms (13.7%). Trials on the double SR task were discarded when RTs were outside the following intervals: 120 ms < double SR RT_1 < 450 ms or 120 ms < double SR RT_2 < 650 ms and 120 ms < double SR 2CR < 450 ms. In total, we discarded 9.0% of trials in the specific double SR condition. These cutoffs were adjusted to our task by taking account of findings on general refractoriness (cf. Schmidt & Lee, 2011). In general RT shorter than the lower boundary might be the result of fast response guesses whereas values longer than the upper boundary are the indication of inattentive response behavior (Whelan, 2008).

Fitting ex-Gaussian Probability Density Functions to RT Data

Because RT data generally do not have a Gaussian distribution but are more like an ex(ponential)-Gaussian distribution (Luce, 1986), that is, a convolution of two additive processes, Whelan (2008) has proposed fitting the ex-Gaussian probability density function (PDF) to the RT data. The ex-Gaussian PDF is described by three parameters: μ *(mu)*, the mean of the Gaussian distributed part, σ *(sigma)*, the standard deviation of this part, and τ *(tau)*, the mean of the exponential part characterizing the skewness of the overall distribution (Burbeck & Luce, 1982; Lacouture & Cousineau, 2008). According to Hervey et al. (2006) and Whelan (2008) parameter μ provides the most reliable estimation of the distribution whereas the parameter τ estimates the proportion of the slower RT within the distribution. This parameter could be affected by slow RTs which are a result of inattentive participant's behavior. On these grounds, we fitted the ex-Gaussian PDF to each participant's RT data so that we could analyze the characteristics of whole distributions. We fitted the data with the DISTRIB-Toolbox (Lacouture and Cousineau, 2008) in MATLAB R2014a (MathWorks, Natick, MA, USA). We estimated parameters of the PDF for each participant using minimum minus LogL estimation; that is, the parameter values that were most likely given the data set. This estimation was performed with a search algorithm known as Simplex. According to Lacouture and Cousineau (2008), using the LogL criterion with the Simplex search algorithm results in the best fit of the parameters of a PDF to the data distribution.

Statistics

For the basic S–R tasks, we used separate 4 (Condition: unspecific SSR, unspecific 2CSR, specific 2CSR, specific 4CSR) × 2 (Group: experts vs. novices) analyses of variance (ANOVA) with repeated measures for the comparison of individual differences between conditions to determine effects for mean RT and the parameters of the ex-Gaussian PDF. We conducted multiple comparison *post hoc* tests to determine the locus of significant differences for the Condition × Group interaction while controlling the family error rate with Bonferroni corrections. An additional *post hoc* 2 (Condition: unspecific SSR, unspecific 2CSR) × 2 (Group: experts vs. novices)

ANOVA was conducted for parameter μ to validate the results of the multiple comparison *t* tests for the Condition × Group interaction.

Separate 2 (Condition: specific 2CSR, double SR RT_2) × 2 (Group: experts vs. novices) ANOVAs with repeated measures for the comparison of individual differences between conditions were used to determine the effects of the double SR task on mean RT and the parameters of the ex-Gaussian PDF. RTs of the specific 2CSR condition served as the control RTs. *Post hoc*, we conducted 3 (Condition: specific 2CSR, double SR RT_1, double SR 2CR) × 2 (Group: experts vs. novices) ANOVAs to compare the slowdown of first RTs in trials on the double SR task in which the first stimulus was followed by the second (double SR RT_1) and in which no second stimulus appeared at all (double SR 2CR) with RTs in the specific 2CSR condition. This slowdown was tested for mean RT and the parameter μ of the ex-Gaussian PDF. We also conducted multiple comparison *post hoc* tests to determine the locus of significant differences while again controlling the family error rate with Bonferroni corrections.

2.3 Results

Basic S–R Tasks

Table 1 reports mean RTs and the values of the ex-Gaussian PDF for RTs of the basic S–R tasks and the statistical results of the four separate 4 (Condition: unspecific SSR, unspecific 2CSR, specific 2CSR, specific 4CSR) × 2 (Group: experts vs. novices) ANOVAs for mean RT and the parameters μ, σ, and τ of the ex-Gaussian PDF. Referring to Whelan (2008), we shall focus on the results of the normal distributed portion of RTs, parameter μ. This parameter provides the most reliable estimation of the distribution. The important effects for this parameter are shown by a significant Condition × Group interaction, $F(2.21,61.95) = 4.55$, $p = 0.012$, $\eta_p^2 = 0.14$. This interaction was also significant for the parameter σ, $F(2.31,64.7) = 4.27$, $p = 0.014$, $\eta_p^2 = 0.13$. *Post hoc* multiple comparisons for parameter μ revealed significant effects of only shorter RTs for the experts on the specific 2CSR (experts vs. novices: $t[28] = 3.37$, $p < 0.01$) and the specific 4CSR condition (experts vs. novices: $t[28] = 3.26$, $p < 0.01$) task, but not for the unspecific SSR, $t(28) = 1.60$, $p = 0.12$, and the unspecific 2CSR condition, $t(28) = 1.00$, $p = 0.32$. An additional *post hoc*

2 (Condition: unspecific SSR, unspecific 2CSR) × 2 (Group: experts vs. novices) ANOVA for parameter μ revealed a significant effect for Condition, $F(1,28) = 42.84$, $p < 0.001$, $\eta_\rho^2 = 0.61$; but not for Group, $F(1,28) = 1.92$, $p = 0.18$, $\eta_\rho^2 = 0.064$; and not for the Condition × Group interaction, $F(1,28) = 0.019$, $p = 0.89$, $\eta_\rho^2 = 0.001$. Significant group effects emerged for parameter μ and also for parameter σ, with shorter RTs for the expert group (see Table 1). These effects together with the significant Condition × Group interaction and its subsequent *post hoc* test results demonstrated that group differences resulted mainly from the two- and four-choice expertise-specific S–R tasks. Figure 3, illustrating the RT distributions for conditions by groups, shows that the distributions for both groups were rather similar for the unspecific S–R tasks but differed for the expertise-specific tasks. In the latter case, the distributions for the novices shifted more to the right, indicating a higher proportion of excessively slow reactions. It was conspicuous that such a skewness could not be found for RTs in the unspecific SSR and particularly not in the unspecific 2CSR task.

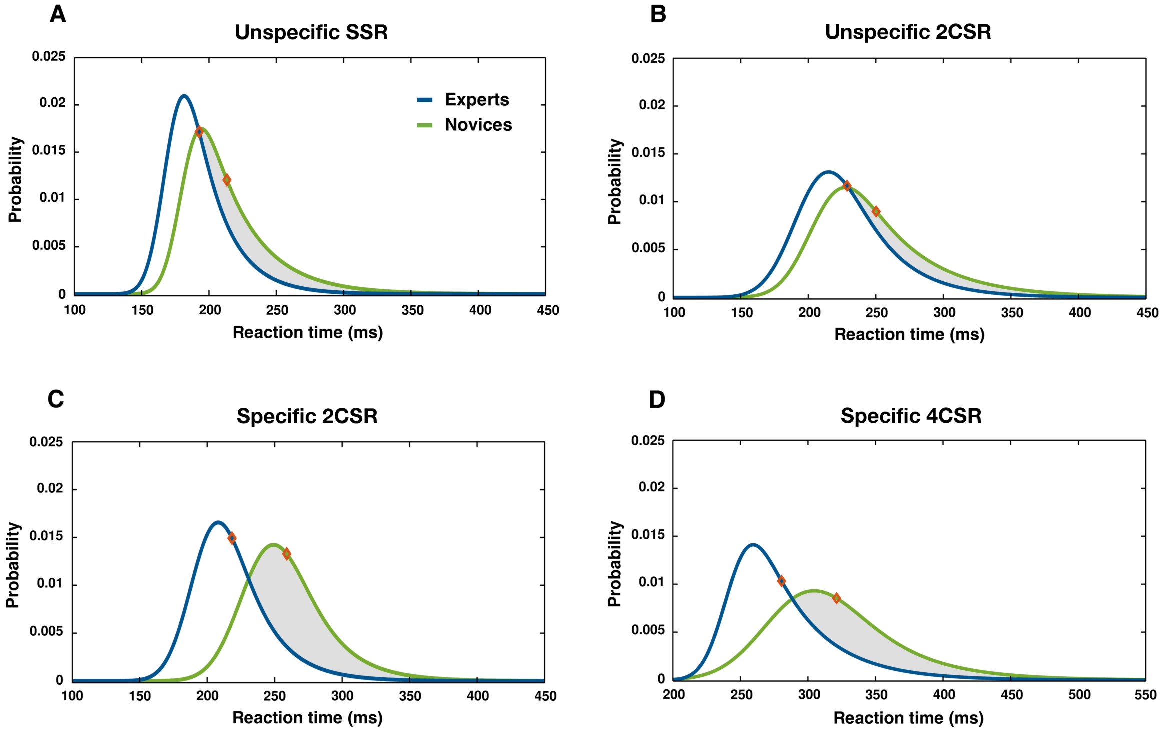

Figure 3 *| Distribution of RT for specific and unspecific basic S-R tasks. Ex-Gaussian PDFs and mean RTs (diamonds) separated by groups for unspecific SSR (A), unspecific 2CSR (B), specific 2CSR (C), and specific 4CSR (D) tasks. Intervals of RT cutoff: (A-C): 120 ms < RT < 450 ms, (D): 220 ms < RT < 550 ms.*

Table 1 | *Average result pattern for basic S-R tasks. Mean reaction times, parameters from fitting the ex-Gaussian distribution, and statistical results of within-subject and between-group effects.*

	Experts, n = 15				Novices, n = 15						
	SSR unspecific	2CSR unspecific	2CSR specific	4CSR specific	SSR unspecific	2CSR unspecific	2CSR specific	4CSR specific	Condition F	Group F	Condition × Group F
Mean RT	192.7 (20.3)	228.7 (24.0)	218.4 (21.0)	280.5 (25.6)	213.3 (25.7)	250.0 (28.6)	258.9 (31.0)	321.2 (29.6)	132.73***	18.0***	2.56
μ (mu)[1]	170.0 (18.0)	196.6 (20.7)	193.8 (24.6)	242.6 (21.0)	181.1 (20.0)	206.6 (32.6)	232.8 (37.5)	279.1 (37.9)	93.59***	9.58**	4.55*
σ (sigma)[1]	11.4 (6.9)	20.1 (8.4)	16.3 (8.6)	14.8 (12.7)	11.2 (8.0)	19.6 (9.7)	20.2 (8.2)	29.8 (14.8)	7.16**	5.17*	4.27*
τ (tau)[1]	22.6 (13.1)	32.1 (14.5)	24.6 (11.3)	37.9 (12.1)	32.2 (15.9)	43.4 (19.6)	26.0 (18.7)	42.1 (12.8)	11.43***	2.74	1.13

[1] *Parameters from fitting the ex-Gaussian distribution to the data. All values are group means in ms, values in parentheses indicate SD. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

Table 2 | *Average result pattern for double SR task. Mean reaction times, parameters from fitting the ex-Gaussian PDF, and statistical results of within-subject and between-group effects.*

	Experts, n = 15		Novices, n = 15				
	2CSR specific	Double SR RT2	2CSR specific	Double SR RT2	Condition F	Group F	Condition × Group F
Mean RT	218.4 (21.0)	262.6 (69.0)	258.9 (31.0)	302.6 (82.8)	10.40**	6.53*	0.00
μ (mu)[1]	193.8 (24.6)	233.4 (77.3)	232.8 (37.5)	267.7 (98.6)	5.11*	4.23*	0.02
σ (sigma)[1]	16.3 (8.6)	41.8 (25.8)	20.2 (8.2)	56.4 (45.4)	20.18***	1.75	0.61
τ (tau)[1]	24.6 (11.3)	29.2 (23.6)	26.0 (18.7)	34.9 (39.5)	0.99	0.31	0.10

[1] *Parameters from fitting the ex-Gaussian distribution to the data. All values are group means in ms, values in parentheses indicate SD. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

Double Stimulus-Response Task

The four separate 2 (Condition: specific 2CSR, double SR RT_2) × 2 (Group: experts vs. novices) ANOVAs revealed a significant effect of Condition for the parameter μ, $F(1,28) = 5.11$, $p = 0.032$, $\eta_{\rho}^2 = 0.15$; and σ, $F(1,28) = 20.18$, $p < 0.001$, $\eta_{\rho}^2 = 0.42$, of the ex-Gaussian PDF with longer RTs and a highly increased variance of distributions for the second RT (RT_2) in comparison to the specific 2CSR condition. This clearly revealed the typical effects of PRP tasks. Additionally, we found a significant effect of Group for parameter μ, $F(1,28) = 4.23$, $p < 0.05$, $\eta_{\rho}^2 = 0.13$, with generally shorter RTs for the experts, thereby underlining the general RT advantage of the expert group in specific S–R tasks. There were no significant effects for the Condition × Group interaction (see Table 2). The ex- Gaussian PDFs by groups are illustrated in Figure 4, and average values with statistical results are reported in Table 2. *Post hoc* 3 (Condition: specific 2CSR, double SR RT_1, double SR 2CR) × 2 (Group: experts vs. novices) ANOVAs to control for the RT slowdown of all first responses on the double SR task (double SR RT_1, double SR 2CR) in comparison with the RTs of the specific 2CSR condition showed significant effects of Condition (μ: $F[2,56] = 28.82$, $p < 0.001$, $\eta_{\rho}^2 = 0.51$) and Group (μ: $F[1,28] = 9.45$, $p = 0.005$, $\eta_{\rho}^2 = 0.25$) with slower RTs for the novices, but no Condition × Group interaction (see Table 3). *Post hoc* multiple comparisons for parameter μ for conditions revealed a significant effect for the comparison double SR RT_1 versus 2CSR, $t(29) = 6.5$, $p < 0.001$, with slower reactions for the first responses on the double SR task, but not for double SR 2CR versus 2CSR. Additionally, we found a significant effect for the comparison between the first responses in which S1 was followed by S2 and in which no second stimulus was presented at all (double SR RT_1 vs. double SR 2CR: $t[29] = 6.78$, $p < 0.001$). Surprisingly, participants showed slower reactions when the first response was

Table 3 | *Slowdown of reactions (RT_1, 2CR) in the specific double SR task. Average values and statistical results of the comparison with the specific 2CSR task.*

	Experts, *n* = 15			Novices, *n* = 15					
	2CSR specific	Double SR RT1	Double SR 2CR	2CSR specific	Double SR RT1	Double SR 2CR	Condition *F*	Group *F*	Condition x Group *F*
Mean RT	218.4 (21.0)	266.2 (35.5)	244.3 (30.8)	258.9 (31.0)	292.1 (33.8)	271.6 (27.7)	31.96***	11.03**	1.26
μ (mu)[1]	193.8 (24.6)	240.7 (43.5)	209.4 (37.6)	232.8 (37.5)	276.1 (37.9)	239.1 (35.8)	28.82***	9.45**	0.29

[1] *Parameters from fitting the ex-Gaussian distribution to the data. All values are group means in ms, values in parentheses indicate SD. *p < 0.05, **p < 0.01, ***p < 0.001.*

followed by a second. Table 3 reports the results of the repeated measures ANOVAs and the average values for RT slowdown.

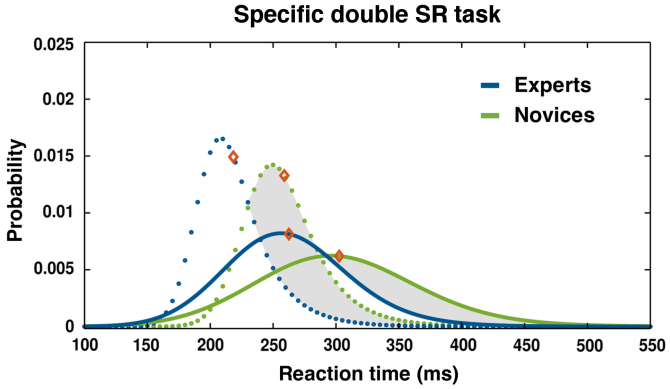

Figure 4 *| Distribution of RT for specific double SR task. Ex-Gaussian PDF and mean RTs (diamonds) for* RT_1 *(dashed lines) and* RT_2 *(solid lines) separated by groups. Intervals of RT cutoff: 120 ms <* RT_1 *< 450 ms, 120 ms <* RT_2 *< 650 ms.*

2.4 Discussion

The present study used expertise-specific and unspecific S–R tasks to investigate the effects of motor expertise on the speed of internal perceptual-motor processing. The main goals were twofold: first, we wanted to investigate whether motor experienced athletes (team handball goalkeepers) would show a superior performance in basic perceptual-motor processing; and second, we wanted to identify whether the predicted expertise advantage would be due only to the processing of domain-specific movements or would be a general advantage. By examining the whole RT distribution, we were able to perform a detailed and comprehensive analysis and detect effects that would otherwise have been missed. In general, our results replicate early findings showing an increase in RTs associated with an increase in S–R alternatives (Hick, 1952; Hyman, 1953). Our main results are as follows: first, experts tend to show, on average, quicker reactions than novices. Second, experts specifically show a significant advantage on domain-specific S–R tasks, whereas novices tend more frequently to produce excessively long RTs on such tasks. Third, experts and novices show different RTs in a double-response paradigm. The following sections will discuss these results in detail.

Effects of Motor Expertise on Basic Internal Perceptual-Motor Processing

One often reported assumption regarding expertise research in sports is that the production of fast RTs by skilled athletes is grounded mainly in an advantage of anticipatory perceptual processes rather than in an efficiency of basic perceptual-motor processing for domain-specific movement tasks resulting from the expertise motor experience. Within this context, our results demonstrate that it is not exclusively superior anticipatory performance, but especially an efficiency of perceptual-motor processing on domain-specific movement tasks that induces fast reactions in skilled (motor experienced) athletes. Our results also support findings on action prediction research in the sport domain, showing that the expertise advantage increases when athletes are required to perform specific sports-related reactions during more natural paradigms (Farrow & Abernethy, 2003; Mann et al., 2010; Travassos et al., 2013).

Up to now, only a few studies have shown a reduction in averaged RTs and RT variability as a result of practice (Mowbray & Rhoades, 1959; Rabbitt & Banerji, 1989). In relation to our study design, we note explicitly that our expertise-specific response tasks are classified as being similar to a typical defensive reaction by a team handball goalkeeper. This implies that our specific S–R tasks have not been practiced in their task-specific manner by one group or the other. It is only the practice of a similar domain-specific reaction (the goalkeeper’s save) that is taken into account for the expertise of the goalkeeper, because the experimental tasks differed only across the required movement responses, but not with respect to the figuration of presented stimuli.

Taking all this together, we suggest that practicing perceptual-motor tasks enhances the processing of other related domain-specific S–R tasks which require different movement responses. The fact that the expert group shows less variation on the specific S–R tasks supports this line of reasoning. One central assumption of (sensory motor) learning theory and expertise performance is that practice produces an acquired capability for skilled movements that generates a “storage” of refined internal (sensory motor) representations (Ericsson & Smith, 1991; Beilock, Wierenga, & Carr, 2003; Ericsson, 2003, 2007; Frank, Land, & Schack, 2013). These circumstances could either bypass or inherently alter the basic limits of internal processing through training (Ericsson, 2003). We argue that experienced goalkeepers establish these sensory motor representations while performing domain-specific reactions over their years of training. We suggest that recalling these stored representations facilitates internal perceptual-motor processing; and that it was this that resulted in faster RTs in our expertise-specific S–R tasks. This indicates that domain-specific (perceptual-motor) training facilitates not only anticipatory perceptual processes (Farrow & Abernethy, 2002; Williams et al., 2011) but also, and especially, internal perceptual-motor processing. The effects might become even stronger with an increased amount of practice or movement experiences over the life span as reported in expertise research (Ericsson, Krampe, & Tesch-Römer, 1993). That this strong facilitation does not hold for the unspecific S–R tasks demonstrates the aforementioned notion that perceptual-motor training produces specific effects that do hardly transfer to other skills. The goalkeepers' perceptual-motor expertise does not facilitate the internal processing of domain-unspecific S–R tasks. In this context, we cannot totally rule out that quicker responses by athletes are not a general RT phenomenon (i.e., selection process), but our data indicate that a stronger facilitation of internal processing might be a result of perceptual-motor expertise in performing domain-specific and integrated responses (i.e., training process). However, the RT distributions in the unspecific S–R tasks already indicate that novices tend more frequently to produce long RTs than experts do. Indeed, although differences are not statistically significant, the possibility that early selection processes lead to only athletes with better internal processing abilities remaining in the goalkeeping domain cannot be precluded.

Taking traditional information processing models into account (cf. Donders, 1869/1969; Sternberg, 1969), we propose that the efficiency of internal processing in the expertise-specific tasks is driven by a more efficient response processing stage. By separating the processing stages of such simplified models into the stages of stimulus (perceptual) and response (motor) processing, we argue that our specific and unspecific 2CSR tasks differ only in terms of different motor responses to be made as a reaction to the same stimuli. Our results revealing no significant differences in RTs between groups in the unspecific but significant differences in the specific 2CSR tasks and therefore indicate an efficiency of response (motor) processing in experts.

Double Stimulus-Response Task

As stated above, we assumed that our double-response task would be grounded in the same mechanisms as those described for the PRP paradigm. In this context, our results reveal a similar pattern to early findings reported by Welford (1968) showing an increase of RTs for the second reaction in comparison to an analogous choice RT in which only one stimulus is presented. Further, the reported group effects account for an overall expertise advantage in that task, however, results do not show whether motor expertise particularly facilitates the processing of S2. This is in contrast to findings showing that dual-task costs decrease with the level of practice (Gottsdanker & Stelmach, 1971; Van Selst et al., 1999), indicating first and foremost that experienced team handball goalkeepers do not totally benefit from their internal representations when performing this task. On further consideration, we suggest that the missing effect could imply that goalkeepers do not reprogram their actions in a real situation.

We propose two different lines of reasoning: first, goalkeepers tend to react to all types of throws regardless of whether they are deceptive or non-deceptive. Additionally, Cañal-Bruland and Schmidt (2009) have shown that team handball goalkeepers are biased to view a 7-meter throw as deceptive. These results could support our findings showing a slowdown of RT for the first responses on all trials of the double SR task, even though all of these responses that the participants had to make were embedded in the context of a 2CSR task. What is surprising is the effect that RT_1 was, on average, slower than the reactions on the 2CR trials. This signifies that participants especially show a longer processing of the first reactions when S1 is followed by S2. *A priori*, we predicted only the reversed interference effect. We would argue that because S2 occurs at such an early point in time during the processing of S1, it leads to a delay in processing. Findings in the context of cost–benefit analysis for the effect anticipation might support this notion. Several studies have shown that the inhibition of an already planned action requires more processing time considered as the cost of (re)acting incorrectly (Schmidt & Gordon, 1977; Posner, Nissen, & Ogden, 1978). In general, this phenomenon could have exerted a decisive influence on the nature of internal processing in the double SR task, and could have eliminated significant differences in processing times between groups. It seems that the emergence of S2 at this point in time influences the processing of S1, and this eliminates the potential efficiency of recalling internal representations.

The second line of reasoning focuses on the nature of interactions between a goalkeeper and a field player in a real 7-m penalty situation. Considering the time window in which goalkeepers can recognize a deceptive movement and the start of an ongoing throw, goalkeepers might have enough time to process each event separately. This implies that they have enough time to finish reacting to the field player's first movement, to move back to their initial position, and to start a possible second response. Consequently, a typical reprogramming of movements may well be unnecessary in the majority of real- life 7-m penalty situations. This is why the goalkeepers' domain-specific perceptual-motor expertise will not help to facilitate the internal processing of the double-response task, in particular processing of S2. Post hoc, we consider that this task is probably unspecific in the goalkeeper's domain. However, we deliberately chose an SOA of 156 ms in our paradigm to force participants not to process the two stimuli either grouped together or one after the other, respectively not independently. Due to both a goalkeeper's predisposition to judge actions as deceptive and the short time interval between the first and the second stimuli, goalkeepers might have deliberately slowed down their first reaction, and this would account for the lack of any effect of RT differences between experts and novices in the second reaction. The effect of slowdown in the novice group could be explained through cost–benefit trade-offs (cf. Schmidt & Gordon, 1977; Posner et al., 1978). We would suggest that the costs of being deceived on a double SR trial would be reduced by a (general) RT slowdown, and that this would facilitate correct responses.

Conclusion

The present data reveal that motor expertise with its associated internal representations explicitly facilitates the perceptual-motor processing of domain-specific S–R tasks. Mowbray and Rhoades (1959) have already shown that practice of a traditional RT task increases the speed of internal processing. Our data extend this by showing these effects of efficiency for the processing of S–R tasks in the context of an expertise domain specificity. Due to the elimination of anticipatory perceptual behavior in the experimental tasks, this efficiency can be seen to result from expertise based on motor experience. The contrasting findings between our domain-specific and domain-unspecific S–R tasks indicate that the goalkeepers' perceptual-motor expertise is beneficial in other tasks only within their specific perceptual-motor domain. Nonetheless, we cannot rule out the possibility that this expertise (team handball goalkeeping) leads to a general advantage in the processing of S–R tasks.

The data also reveal that the internal processing of a second stimulus that closely follows a first stimulus generally takes longer in comparison to a task in which only one stimulus is presented. In particular, our data indicate that this delay in processing affects the processing of not only the second but also the first reaction—as indicated by slower reactions in comparison to a control task. We conclude that behavioral effects of a cost–benefit trade-off influence the internal perceptual-motor processing in a real-world double stimulus-response task in general. However, our double-response task shows that further research needs to explore the nature of movement reprogramming for skilled sports performance in real-world situations.

Turning to applied contexts, we emphasize that fast reactions of athletes are not grounded exclusively in an advantage regarding action prediction, but especially in an advantage regarding internal perceptual-motor processing.

3 Effector-Specific Deceptive and Non-Deceptive Movements: Analysis and Synthesize of Movement Patterns

A similar version of this chapter has been submitted for publication in
Human Movement Science as:

Helm, F., Munzert, J., & Troje, N. F. — Effector-Specific Movement Deceptions:
A Kinematic Analysis.

The present study examined differences in deceptive and non-deceptive handball throws between expert and novice athletes. The motion data of 1,580 (788 deceptive) 7-m penalty throws by novice and expert handball field players were analyzed with linear discriminant (LDA) and dissimilarity analysis. Results of the LDA showed that discrimination between deceptive and non-deceptive (genuine) throws was more error-prone when throws were performed by experts (spatial: 4.6%; temporal: 29.6%) compared to novices (spatial: 1.0%; temporal: 20.2%). The dissimilarity analysis revealed that spatial dissimilarities and variations between types of throws were significantly smaller in experts compared to novices ($p < 0.001$). However, temporal dissimilarities did not differ significantly between groups. We concluded that expertise in performing deceptive movements results in the ability to perform deceptions that are highly similar to genuine movements. This expertise is suggested to depend mainly on keeping spatial dissimilarities small. Furthermore, the results of the LDA and its computed linear classifiers provide a reliable basis to synthesize new throwing patterns that differ in the degree to which they are deceptive or non-deceptive.

3.1 Introduction

In daily life, various types of human interaction require the identification of other people's action intentions. This makes it possible to adapt own behavior to an interacting counterpart. In the majority of situations, human actors are extremely sensitive to quickly and efficiently recognize other people's action intentions (Blake & Shiffrar, 2007; Frith & Frith, 2006; Troje, 2008; Zentgraf et al., 2011). Such skills are particularly important for success when performing complex movement interactions in sport such as penalty shootouts in hockey or association football. However, in such situations, the penalty takers often deliberately attempt to disguise their real action intentions in order to deceive the goalkeeper. They attempt this within their movement performance. For instance, competitive athletes may try to convince opponents that they are performing one action while actually carrying out another. The aim is to get the goalkeeper to make a prediction error. Nonetheless, research has shown that the human brain is sensitive enough to detect the action intentions behind deceptive movements (Cañal-Bruland et al., 2010; Runeson & Frykholm, 1983; Sebanz & Shiffrar, 2009), although prediction accuracy may be reduced compared to the detection of real action intentions (Dicks et al., 2010a; Grèzes et al., 2004; Jackson et al., 2006; Rowe et al., 2009). Hence, to some degree, humans are able to recognize whether interacting counterparts are genuine or deceptive in their intentions. Whereas perceptual research on deception initially investigated the detection of object-directed deception (Grèzes et al. 2004; Runeson & Frykholm, 1983), sport science has delivered evidence on how the human body can be used effectively as a deceptive instrument and how accurately such deceptive movements can be identified during interaction (Brault et al., 2012; Cañal-Bruland et al., 2010; Güldenpenning, Steinke, Koester, & Schack, 2013; Jackson et al., 2006; Lopes et al., 2014; Sebanz & Shiffrar, 2009).

From a more theoretical point of view, deceptive movements are motor actions performed to intentionally mislead an opponent about one's own real action intentions (Kunde et al., 2011). Deceptive movements can be divided roughly into three main types: first, deceptive actions may be generated by head or gaze movements. So called "head fakes" are one successful way to deceive opponents about the direction of a pass (Kunde et al., 2011). A second type of deception relies on whole-body movements that are used, for example, to mislead an opponent to anticipate the running direction of an attacking player (e.g., side-step in rugby). A third type are more effector-specific deceptions, a potential kind of movement mimicry in which the deceptive action includes the mimicry of a non-deceptive movement; for example, deceiving another when throwing a ball. A deceptive movement is then generally followed by a non-deceptive movement. These type of deceptions are intended to compel a false reaction by an opponent resulting in a competitive advantage for the attacking player (see sections 1.1.2/1.1.3, for a detailed overview) .

It is widely accepted that movement kinematics convey a rich source of information with which to detect deceptive action intentions and to perceptually distinguish deceptive from non-deceptive (genuine) movements (Cañal-Bruland & Schmidt, 2009; Runeson & Frykholm, 1983; Sebanz & Shiffrar, 2009). Genuine and deceptive movements typically display a degree of spatiotemporal dissimilarity in terms of their motion trajectories and the temporal dynamics of their movement kinematics. According to Mather and Murdoch (1994) and Troje (2002), the informational source provided by dynamic features clearly dominates the role of structural cues in the context of action recognition or observation. However, up to now, only a few studies have tried to characterize the nature of kinematic features for deception (Brault et al., 2010; Lopes et al., 2014; Smeeton & Williams, 2012). For instance, Brault et al. (2010) conducted an experiment to directly address this question for one-on-one situations during running in rugby (side-step while approaching an opponent). The most significant angular changes in the initial running path were found for the upper trunk. The minimization of other parameters such as lower trunk movements, for instance, were sought in order to maintain the postural stability needed to change the final running direction. The largest differences were observed in the final phase of the gait cycle. Similar effects were also reported by Lopes et al. (2014) who observed the largest differences between deceptive and non-deceptive penalty kicks close to the moment of ball contact. These findings describe fundamental biomechanical structures and contingencies for deceptive and non-deceptive movement behavior. However, when it comes to the different types of deception, the question still remains how more effector-specific deceptive and non-deceptive movements differ kinematically.

The present study aims to investigate the kinematic characteristics of effector-specific movement deceptions, a potential kind of movement mimicry. More specifically, we shall analyze differences between deceptive and equipollent non-deceptive 7-m penalty throws in team handball. We ask first, how these deceptive and non-deceptive penalties separate kinematically; and second, how this is achieved differently by novice and experienced athletes. We took an analysis approach combining methods from linear statistics with spatial and temporal dissimilarity analysis. This approach will also serve as a basis for the synthesize of new movement patterns in which spatial and/or temporal attributes of the deceptive and non-deceptive throws can be manipulated. Those synthesized movements can then be used in the context of perceptual research. A priori, we predicted a higher linear discriminability between deceptive and non-deceptive throws for novices compared to experienced penalty takers. Moreover, we hypothesized that the dissimilarities and variations between the deceptive and non-deceptive throws would be smaller for throws performed by experienced compared to those performed by novice players.

3.2 Methods

Participants

Ten right-handed male participants volunteered to participate in this study (M_{age} = 22.1 years, SD = 3.5). The study was approved by the local ethics committee of the Justus-Liebig-University Giessen and all participants gave their informed written consent in accordance with the Declaration of Helsinki. Participants were divided into two different expertise groups: experts (competitive elite team handball field players, according to Swann et al., 2015, n = 5) and novices with no previous experiences in team handball other than attending a university class for beginners (n = 5). Athletes from the expert group played in one of the four highest national leagues in Germany and were frequent penalty takers for their team. We considered them to be experts in performing deceptive movements. They reported training for an average of 13 hours per week (SD = 1.9) and had a mean playing experience of 16 years (SD = 2.9).

Apparatus and Design

Four different target locations (1.2 m × 1.2 m) were set up in the upper and lower left- and right-hand corners of a standard handball goal (3 m × 2 m, as specified in the guidelines of the International Handball Federation). Kinematic data were recorded by means of a motion capture system (VICON, Oxford, UK) equipped with 15 CCD high speed cameras and remote-controlled by Presentation software (Neurobehavioral Systems, Albany, NY) running on a control PC. The system tracked three-dimensional trajectories of retroreflective markers with a spatial accuracy of 1 mm and a sampling rate of 240 Hz. During the experimental session, a set of 41 retroreflective markers was attached to the penalty takers whereas the marker placement of the ball consisted of 8 markers. Participants wore tight neoprene shirts and shorts and most of the markers were attached directly to the skin. Others, such as those for the head, the ankles, and the wrists, were attached to elastic bands, and the ones on the feet were taped to the subjects' shoes.

In general, we conducted an in-situational experiment with two expertise groups (novices vs. experts) and two different conditions (deceptive vs. non-deceptive throws) with several variations of deceptive and non-deceptive 7-m penalty throws. In line with the in-situational conditions, goalkeepers with the same skill level as the penalty takers volunteered to participate in order to make the situation as realistic as possible. Table 4 gives a detailed description of the different conditions and their variations.

Table 4 *| Specification and description of all experimental conditions. Bold text indicates variations 1–8 that were used in the data analysis.*

Condition	#	Target location / variation			Description
Non-Deceptive Throws	1	**Upper Right**			Straight throw to the target at the specified target location.
	2	**Upper Left**			
	3	**Lower Right**			
	4	**Lower Left**			
Deceptive Throws	5	**Upper Right (D)**	-	Upper Left (ND)	Deceptive throw (first action) to the target at the specified target location (D), followed by a straight veridical throw (second action) to the then specified target location.
	6	**Upper Left (D)**	-	Upper Right (ND)	
	7	**Lower Right (D)**	-	Lower Left (ND)	
	8	**Lower Left (D)**	-	Lower Right (ND)	
	9	Upper Right (D)	-	Upper Right (ND)	
	10	Upper Left (D)	-	Upper Left (ND)	
	11	Lower Right (D)	-	Lower Right (ND)	
	12	Lower Left (D)	-	Lower Left (ND)	

Procedure

Prior to the experimental block, participants attended a short warm-up session to familiarize themselves with the experimental setting. During the experiment, participants conducted a total of 240 penalties in two conditions with six different variations (20 throws each, see Table 4) including 120 deceptive throws. For these effector-specific deceptions, the penalty taker started to throw, but stopped the throwing movement shortly before possible ball release (deceptive part) and immediately continued the action with a repetition of the throwing movement resulting in a final ball release. Therefore, the deceptive action was based on a deliberate attempt to disguise the intention to abort the first throw. The penalty taker's aim behind this deception was to provoke a false reaction by the goalkeeper. Penalty takers were instructed regarding which type of throw to use (deceptive, non-deceptive) and its target location in a pseudo-randomized order via Presentation software on a screen. This screen was not visible for the goalkeeper. After each block of 60 trials, participants rested for 2 min before continuing the experiment.

Data Analysis

For each field player, deceptive and non-deceptive penalties from Variations 1 to 8 (n = 160; see Table 4) were utilized for data analysis. Variations 9 to 12 were introduced to prevent goalkeepers from developing behavioral strategizing. Thus, goalkeepers were unable to predict upcoming actions in the deceptive trials that otherwise would have influenced the overall goalkeeper versus field player interaction in a way that could have led to the emergence of atypical field player behavior. Trials in which participants failed to throw the ball correctly (e.g., ball dropping) were excluded from data analysis (1.25%). Motion capture data of the field player and the ball were preprocessed in Nexus 1.7 software (VICON, Oxford); further processing was done in MATLAB R2015a (MathWorks, Natick, MA). In the following steps, we utilized the first (deceptive) action part of the deceptive penalty throws and compared these parts with their related genuine (non-deceptive) throws.

Table 5 | *Kinematic characteristics of the five predefined landmarks for the time registration procedure.*

Landmark	Description
t0	Maximum velocity in backswing
t1	Reversal of backswing; equal to zero-crossing in velocity profile
t2	Local maximum in velocity profile; preceding slowdown of the right hand due to tension generation in throwing arm
t3	Local minimum in velocity; marking the transition into final forward acceleration
t4	Max. velocity of throw; equal to hand-ball-release in non-deceptive trials and deploying for predicting 'virtual' hand-ball-release in deceptive trials

Modeling the kinematic data. To analyze the movement variations, we used landmark-based time registration that aligns the time series of predefined movement characteristics in the position and/or velocity profiles of each individual throw to the time series of a general template (see Müller, 2007; Ramsay, Hooker, & Graves, 2009, for overviews). We defined five different landmarks with reference to the position and velocity trajectories in the sagittal plane of the right (throwing) hand. The definition of landmarks is described in Table 5 and illustrated in Figure 5. All throwing

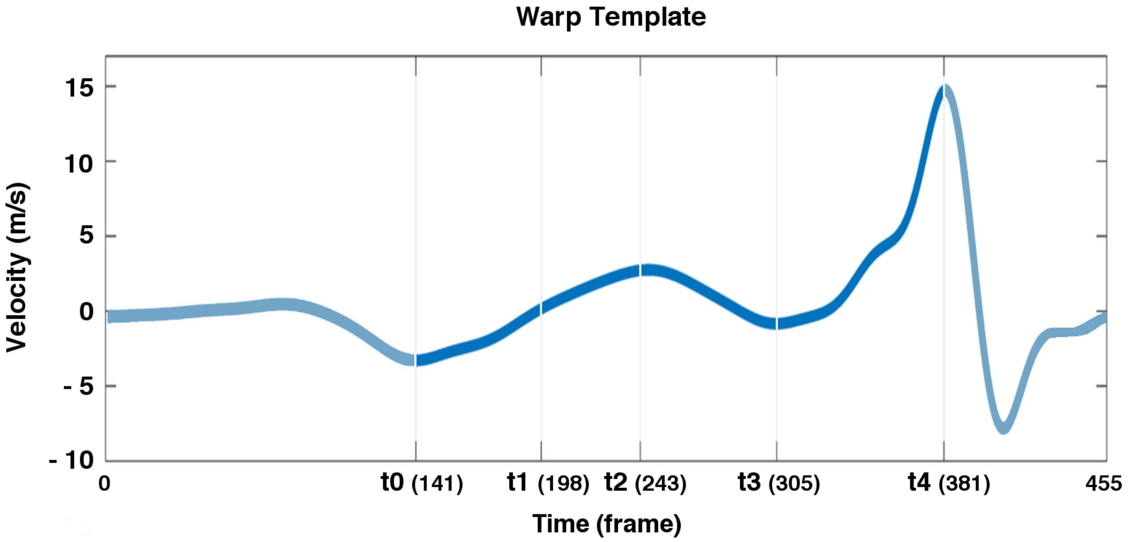

Figure 5 | *Warp template and defined landmarks: Illustration of the landmark definition based on the velocity profile of the right hand for the sagittal plane. The dark blue trajectory describes a representative time sequences used for the analysis procedure.*

sequences were time-warped to 240 frames (1 s) that represented the time course from t_0 to t_4 of the general template (see Figure 5). Additionally, we aligned the initial throwing position of the throwers by defining the three-dimensional position of the left toe marker as the origin of the coordinate system in each trial. Each original throw was then represented in terms of both the time-normalized sequence and the time warp itself.

Classification of time-normalized deceptive and non-deceptive throwing sequences. Each individual time-normalized throw was defined as a time series of different poses specified by the position of the 41 body markers. The representation of a single pose was therefore a 41 × 3 = 123-dimensional vector $\mathbf{p_i = (mp_{1x}, mp_{1y}, mp_{1z}, mp_{2x}, \ldots, mp_{41z})^T}$. Concerning the duration of the throwing sequence of the general template (240 frames), one throw is defined as a 123 × 240 = 29520-dimensional column vector $\mathbf{w_j}$. We used principal components analysis (PCA) to decompose the original data in such a way that they would retain as much variance as possible given any chosen number of components. This procedure was computed separately for each individual participant (Webb, 2002) and also for left- and right-targeted throws. The overall data set for each participant was then described as **W**, which represents a 29520 **x m** matrix with **m** indicating the number of available throws. Computing the PCA on the data, **W** resulted in a decomposition of each throw $\mathbf{w_j}$ into an average throw $\mathbf{w_0}$ and **n** weighted principal components $\mathbf{v_i}$, with $\mathbf{n < m}$.

$$\mathbf{w_j} = \mathbf{w_0} + \sum_{\mathbf{i}} \mathbf{k_{i,j} v_i} \qquad (1)$$

Thus, each individual throw **j** was represented by the respective score vector $\mathbf{k_j = (k_{1j}, k_{2j}, \ldots, k_{nj})^T}$.

Importantly, PCA itself cannot provide movement specific information to differentiate reliably between different types of movements, but rather facilitates the extraction of basic patterns or the identification of invariant properties within the data set (Daffertshofer, Lamoth, Meijer, & Beek, 2004; Schorer, Baker, Fath, & Jaitner, 2007). Thus, in a next step, we applied linear discriminant analysis (LDA) to the data derived from the PCA in order to test (a) how deceptive and non-deceptive throws separate linearly and (b) how linear classifiers generalize to new instances that have not been used for training of the classifier. Based on the derived decomposition of our original data set **W**, defined in Equation 1, the representation of the overall data set was described as **K**, which is an **n x m** matrix. The matrix **K** contains the score vectors $\mathbf{k}_{i,j}$, obtained by solving Equation 1. Varying **n**, the number of principal components, we then computed a linear classifier **f** by solving the over-constrained linear equation system

$$fK = r \qquad (2)$$

according to a least-square criterion. Vector **r** was defined by group membership of the respective throws. Besides the possibility of computing a separation plane between the deceptive and non-deceptive throws (training of the linear classifier), we also used cross-validation procedures to test the generalizability of the subject-wise classifier. In this procedure, one of the **j** throws was taken out of our data set and a linear classifier was computed on the remaining **j-1** throws as described in Equation 2. The linear vector of the previously taken out throw was then projected onto the classifier in the subspace spanned by the principal components and we evaluated whether it was classified correctly. This procedure was repeated with all throws for each participant.

Classification of deceptive and non-deceptive time warps. For the classification procedure of the time warps, we also applied PCA and LDA by following the same steps described for the classification of the time-normalized throwing sequences. Only the structure of the used input data was different. Resulting from the five predefined landmarks, we obtained a five-dimensional column vector $\mathbf{w}_j = (\mathbf{t}_0, \mathbf{t}_2, \ldots, \mathbf{t}_4)^T$ as the time warp for each individual throw. The resulting four principal components were used for the linear classification.

Another advantage of computing linear classifiers for the kinematic throwing data is that these classifiers can be used to synthesize throwing patterns that differ in the degree to which they are deceptive. This is achieved by varying the amount of spatial and temporal dissimilarity between synthesized throws and the averaged (non-)deceptive throw (cf. Troje, 2008).

Dissimilarity analysis. Whereas the LDA indicates to which degree different types of throws separate, other methods are required to further describe the differences in movement characteristics between the deceptive and non-deceptive penalty throws. We therefore conducted a spatial and temporal dissimilarity analysis. Euclidean distances between the marker positions of the deceptive and non-deceptive throws were computed by means of the derived linear classifiers **f** of the time-normalized throwing sequences. All individual deceptive throws were reconstructed by projecting them onto the classifier **f**. Further, we computed the Euclidean distance **d** between each of these reconstructed deceptive and the reconstructed averaged non-deceptive throws. This was completed for different body parts (head, torso, pelvis, r*ight*ArmHand, r*ight*LegFoot, l*eft*ArmHand, l*eft*LegFoot) as well as over time **t**. The averaged spatial dissimilarity per frame was then calculated based on the Euclidean distance **d** over time **t**. A 7 (Body part: head, pelvis, torso, rArmHand, rLegFoot, lArmHand, lLegFoot) × 2 (Target: left vs. right) × 2 (Group: novices vs. experts) mixed design ANOVA with repeated measures for the comparison of individual differences between body parts and targets was calculated to determine the effects of spatial dissimilarity.

The temporal dissimilarity between the landmarks of deceptive and non-deceptive throws was analyzed by means of the classifiers **f** from the classification of the time warps. Each individual deceptive time warp was reconstructed by projection onto the classifier **f.** We then computed the time offset between each individual deceptive and the averaged reconstructed non-deceptive time warp. We used a 4 (Time offset: t_1, t_2, t_3, t_4) × 2 (Target: left vs. right) × 2 (Group: novices vs. experts) mixed design ANOVA with repeated measures for time offsets and for targets to determine the effects of temporal dissimilarity for the different landmarks (cf. Table 5).

Velocity and acceleration of throws. Based on the results of the spatial and temporal dissimilarity analyses, we analyzed the velocity and acceleration trajectories of the deceptive and non-deceptive penalty throws post hoc by reconstructing the original throws by means of the results from the linear classification of the time-normalized throwing sequences and the time warps. We computed the maximum velocity and acceleration of each individual throw. Repeated 2 (Condition:

non-deceptive vs. deceptive) × 2 (Target: left vs. right) × 2 (Group: novices vs. experts) mixed design ANOVAs with repeated measures for conditions and targets were used to determine differences between the movements in terms of velocity and acceleration.

3.3 Results

Linear Classification of Time-Normalized Throwing Sequences

The decomposition of the movement patterns derived from the PCA showed that across all participants, the first 15 principal components accounted for an average of more than 95% of the overall variance of the movement kinematics. Therefore, we used only the scores of these 15 principal components for the LDA. Figure 6 illustrates the results on discriminability in terms of the number of misclassifications after training the classifier (training errors) and misclassifications of the cross-validation (testing errors) as functions of **n**, the number of components used for the classification procedure. Results for the training errors showed that, on average, the classification of novices' throws reached an almost perfect discriminability with 9 principal components (4 misclassifications out of 790 throws, approx. 0.6%), whereas the expert group reached an optimum with 13 principal components

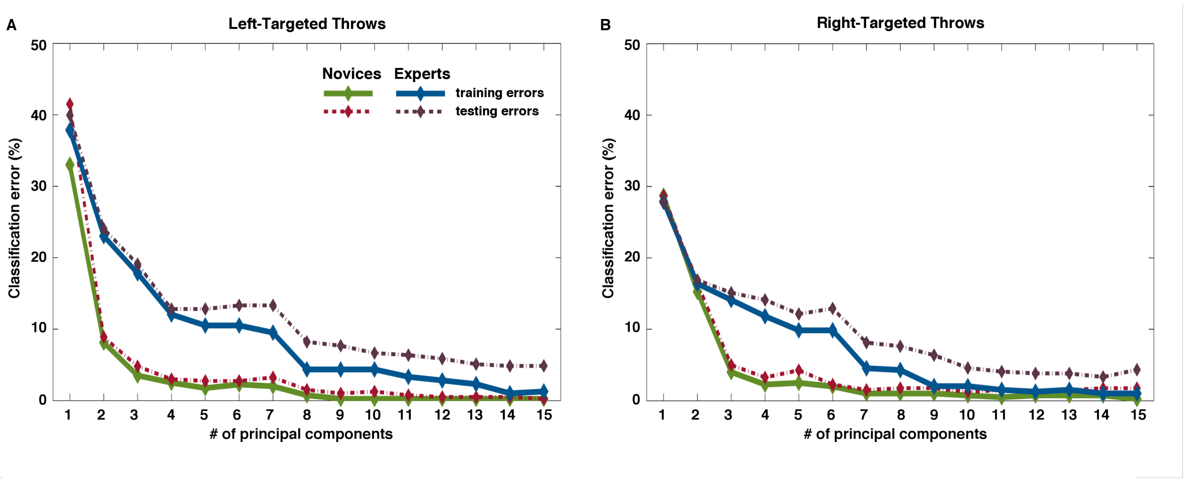

***Figure 6** | Classification errors of the time-normalized position data: Illustration of training errors (solid lines) and testing errors (dashed lines) for left-targeted (A) and right-targeted (B) throws separated by groups (novices; experts).*

(15 misclassifications out of 790 throws, approx. 1.9%). The results of the cross-validation (testing errors) showed that the generalization to new data from the same participant was performed more inaccurately for experts compared to novices. The proportion of misclassifications for the cross-validation ranged between 0.3% and 1.8% for novices and between 4.3% and 4.9% for experts.

Linear Classification of Time Warps

Figure 7 illustrates the results of the classification errors derived from the LDA of the deceptive and non-deceptive time warps. The discrimination of the time warps was less accurate than the discrimination of the time-normalized throwing sequences. The averaged training error for left- and right-targeted throws for all principal components was 26.9% for experts and 17.7% for novices. The results of the cross-validation (testing error) showed a similar pattern (see Figure 7). Thus, classification of the time warps was much less accurate than classification of the time-normalized position data. Yet, differences between groups indicated that the classification was more accurate for novices than for experts.

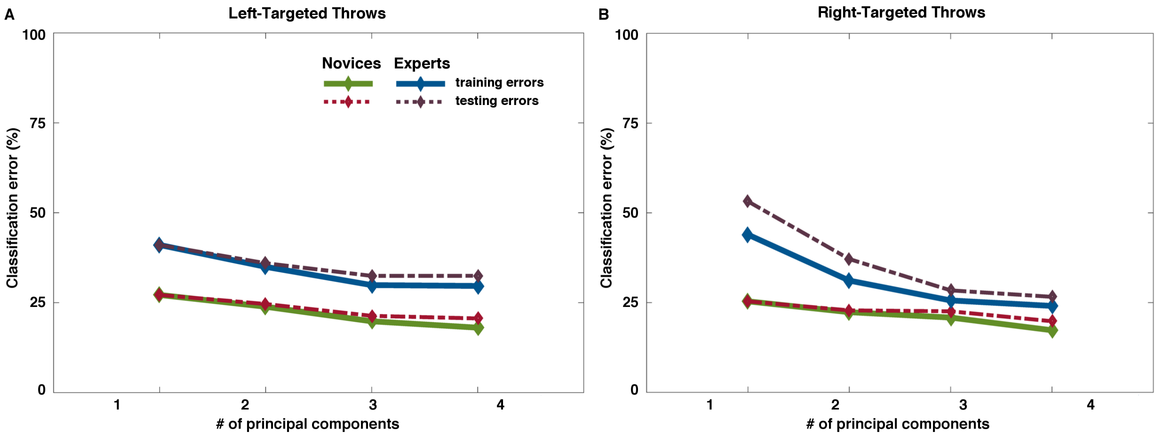

Figure 7 | Classification errors of the time warp data: Illustration of training errors (solid lines) and testing errors (dashed lines) for left-targeted (A) and right-targeted (B) throws separated by groups (novices; experts).

Dissimilarity Analysis

Figures 8 and 9 depict the results of the *spatial dissimilarity analysis*. The spatial dissimilarity analysis of the deceptive and non-deceptive throws (Figure 8) indicated that the greatest dissimilarity over time originated in upper body parts such as left and right arm–hand regions. Specifically, the most significant dissimilarity could be identified for the left (nonthrowing) arm–hand region. The difference between deceptive and non-deceptive trials increased significantly closer to hand–ball release for both the novice and expert penalty takers (cf. Figure 8). A 7 (Body part: head, torso, pelvis, rArmHand, rLegFoot, lArmHand, lLegFoot) × 2 (Target: left vs. right) ×

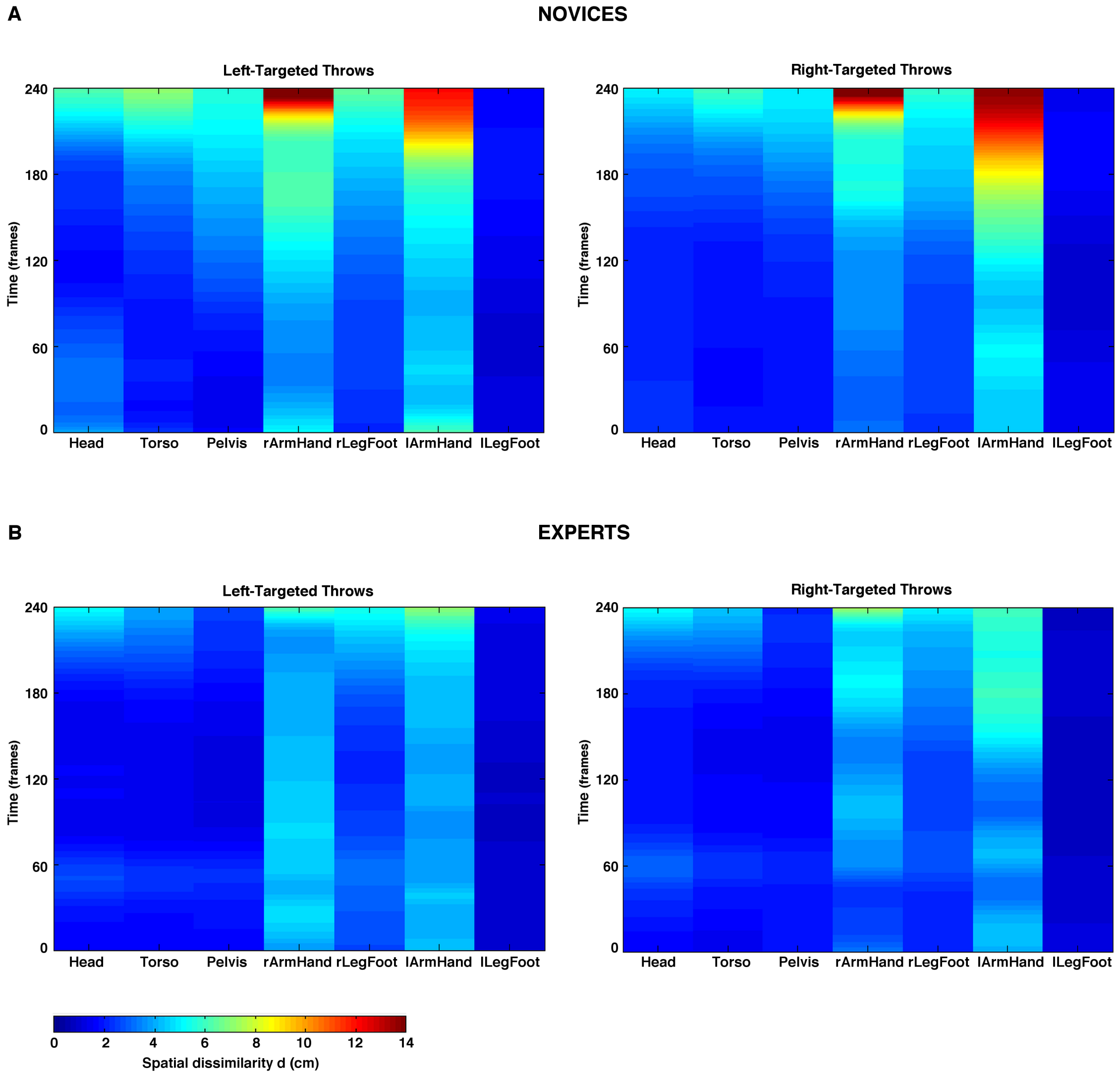

Figure 8 *| Spatial dissimilarity over time: Results of the dissimilarity analysis for specified body parts separated by groups (A: novices; B: experts) and target locations (left, right).*

2 (Group: novices vs. experts) mixed ANOVA on the averaged spatial dissimilarity with repeated measures for body parts and targets revealed a significant main effect for Body part, $F(6, 48) = 27.71$, $p < 0.001$, $\eta_{\rho}^2 = 0.776$, with the highest dissimilarities in the left arm–hand ($M = 9.7$ cm, $SE = 0.9$) followed by the right arm–hand region ($M = 8.3$ cm, $SE = 0.7$); and a significant main effect for Group, $F(1, 8) = 5.77$, $p = 0.043$, $\eta_{\rho}^2 = 0.419$, with larger differences for novices ($M = 6.61$ cm; $SE = 0.5$) than for experts ($M = 4.49$ cm; $SE = 0.3$). Differences between left- and right-targeted throws did not attain significance, $F(1, 8) < 1$, *ns,* $\eta_{\rho}^2 = 0.046$. Two-way interactions were not significant for either Body part × Target, $F(6, 48) < 1.5$, *ns,* $\eta_{\rho}^2 = 0.157$; Body part × Group, $F(6, 48) < 1.55$, *ns*, $\eta_{\rho}^2 = 0.162$; or Target × Group, $\mathrm{F}(1, 8) < 1$, *ns,* $\eta_{\rho}^2 = 0.029$. The three-way interaction Body part × Target × Group also failed to attain significance, $F(6, 48) < 1$, *ns,* $\eta_{\rho}^2 = 0.09$.

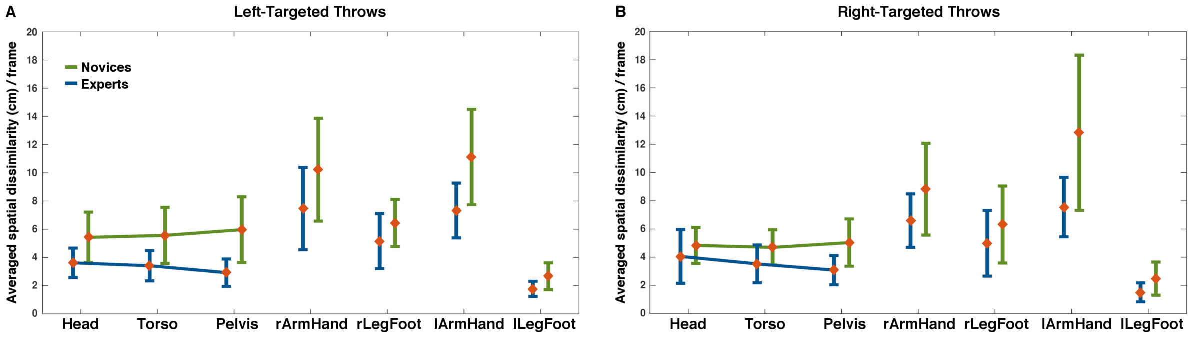

***Figure 9** | Averaged spatial dissimilarity per frame: Dissimilarity for specified body parts separated by groups (expert, novices) and target locations (A: left, B: right). Error bars represent SD of the group mean.*

The results of the *temporal dissimilarity analysis* showed an average temporal difference of 3.3 frames (13.8 ms) between the deceptive and non-deceptive throws (cf. Figure 10), but there were no significant differences between the temporal onset of the predefined landmarks for groups and targets. The results of a 4 (Time offset: t_1, t_2, t_3, t_4) × 2 (Target: left vs. right) × 2 (Group: novices vs. experts) mixed ANOVA with repeated measures for time offsets and targets showed neither a significant main effect for Time offset, $F(3, 24) < 1$, *ns,* $\eta_{\rho}^2 = 0.055$, Target, $F(1, 8) < 1$, *ns,* $\eta_{\rho}^2 = 0.045$, and Group, $F(1, 8) < 1$, *ns,* $\eta_{\rho}^2 = 0.057$; nor any two-way, $F(1, 8) < 1$, *ns,* $\eta_{\rho}^2 = 0.013$; $F(3, 24) < 1.5$, *ns,* $\eta_{\rho}^2 < 0.155$, and three-way, $F(3, 24) < 1$, *ns,* $\eta_{\rho}^2 = 0.108$, interaction effects.

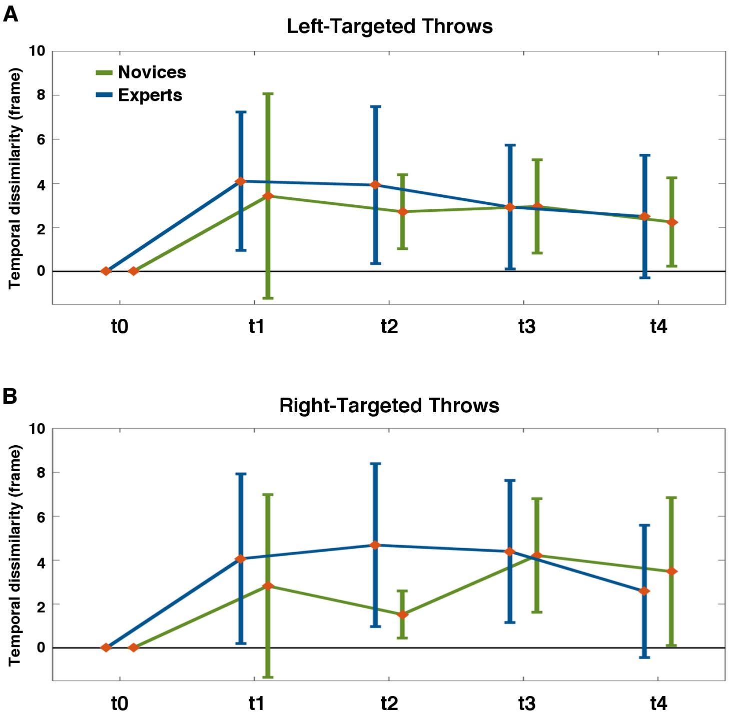

***Figure 10* |** *Temporal dissimilarity: Dissimilarity of temporal occurrence of the defined landmarks (t_0–t_4) separated by groups (novices, experts) and target locations (A: left, B: right). Error bars represent SD of the group mean.*

Velocity and acceleration of throws. The statistical analysis of these parameters revealed significant differences for the maximum velocities and accelerations between deceptive and non-deceptive throws. A 2 (Condition: non-deceptive vs. deceptive) × 2 (Target: left vs. right) × 2 (Group: novices vs. experts) mixed ANOVA for maximum velocity showed a significant main effect only for Condition, $F(1, 8) = 36.23$, $p < 0.001$, $\eta_\rho^2 = 0.819$, but not for Target, F(1, 8) < 1, *ns,* $\eta_\rho^2 = 0.027$, or Group, $F(1, 8) < 1$, *ns,* $\eta_\rho^2 = 0.001$. On average, maximum velocity for the non-deceptive throws (M = 14.52 m/s, SE = 0.51) was higher in comparison to the maximum velocity of the deceptive throws (M = 9.2 m/s, SE = 0.67). Two-way and three-way interactions did not attain significance, $F(1, 8) < 2.46$, *ns,* $\eta_\rho^2 < 0.236$. A 2 × 2 × 2 mixed ANOVA for maximum acceleration showed a similar pattern of results with only a significant main effect for Condition, $F(1, 8) = 9.53$, $p = 0.015$, $\eta_\rho^2 = 0.544$, but not for Target, $F(1, 8) < 1$, *ns,* $\eta_\rho^2 = 0.043$, or Group, $F(1, 8) < 1$, *ns,* $\eta_\rho^2 = 0.076$. Two-way and three-way interactions did not attain significance, $F(1, 8) < 1.1$, *ns,* $\eta_\rho^2 < 0.117$. Thus, both maximum velocity and maximum acceleration showed higher values in the non-deceptive than in the deceptive throws. Figure 11 exemplifies the pattern of results separated by groups and targets.

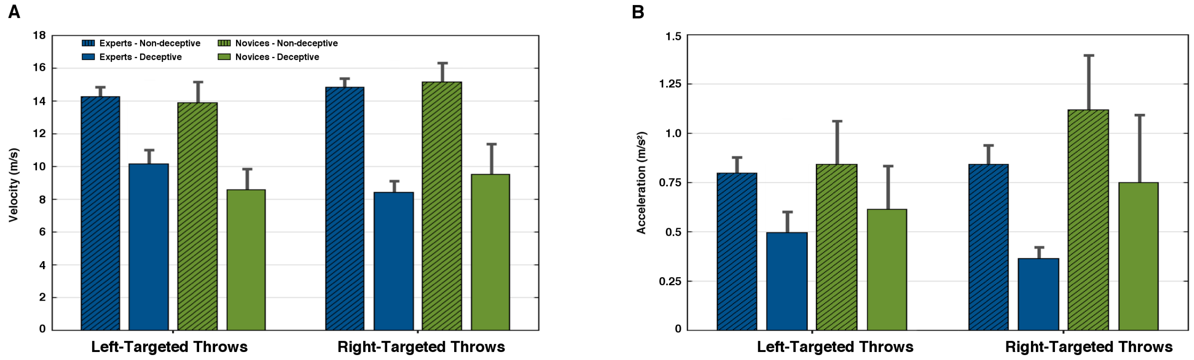

***Figure 11** | Velocity and acceleration of throws: Maximum velocities (A) and accelerations (B) for the deceptive and non-deceptive spatial and temporal reconstructed throws separated by groups (novices, experts) and target locations (left, right). Error bars represent SE of the group mean.*

3.4 Discussion

In the present study, we combined linear statistics (PCA, LDA) with spatial and temporal dissimilarity analysis to investigate the kinematics of effector-specific movement deceptions. In general, the data demonstrate that movement patterns discriminate in a linear way between deceptive and non-deceptive penalty throws, but that classification is more error-prone for expert in comparison to novice athletes. The following section will discuss the present data with respect to the kinematic characteristics of effector-specific movement deceptions and with respect to different body parts. In addition, implications for real-time field situations will be considered.

Kinematic Characteristics of Effector-Specific Movement Deceptions

Deceptive movements are characterized by complex spatiotemporal motion patterns that are determined by both biomechanical and individual constraints. With our present data, we provide evidence that the acquisition of expertise through years of extensive training in performing deceptive movements results in the ability to highly minimize the dissimilarities between deceptive and non-deceptive (genuine) throws. Expertise research on action recognition provides some evidence for the effectiveness of deceptive actions performed by experienced athletes. For instance, it has been shown that the perceptual recognizability of deceptive actions decreases in comparison to the recognition of genuine actions (e.g., Grèzes et al., 2004; Jackson et al., 2006; Rowe et al., 2009). This might be a result of minimizing dissimilarities between the types of movements. Our kinematic data demonstrate that the spatial differences in the movement kinematics between deceptive and non-deceptive throws were significantly smaller for experts in comparison to novices. This might also illustrate why defense players potentially have more difficulties in recognizing deceptions when they are performed by experts in comparison to recreational athletes (Jackson et al., 2006). However, experts were not able to reduce the dissimilarities between types of throws to its full extent. This is in line with other findings and can be explained by the non-substitutability of genuine actions (Jackson et al., 2006; Richardson & Johnston, 2005; Runeson & Frykholm, 1983). This let us suggest that it seems possible to create some of the kinematic details of the corresponding non-deceptive movement when performing a deception, but not all of its full details. Regarding the significant differences between groups with higher dissimilarities for novices' throws in the spatial, but not the temporal component, we suggest that the expertise in performing effector-specific movement deceptions, a potential kind of movement mimicry, is determined mainly by keeping spatial dissimilarities small.

With respect to the maximum velocity and acceleration of the throwing arm, we argue that the higher values for non-deceptive throws for both expertise levels are a result of the idiosyncratic biomechanical constraints on performing deceptive movements. The assimilation of velocity and acceleration to the same level found in non-deceptive movements is limited when performing a deception. This is determined by the fact that high action forces, resulting from the movement of the throwing arm, must be avoided during deceptive movements in order to maintain the necessary postural stability to successfully proceed to the upcoming throwing action. The importance of keeping postural stability available while performing deceptive movements has also been shown in the context of movement deceptions while running (Brault et al., 2010). Otherwise, high action forces are required in genuine movements in order, for instance, to transfer the kinetic energy to the ball. Thus, the different action requirements and the related velocities and accelerations of the throwing arm clearly demonstrate biomechanical limitations to mimicking the genuine movement while performing a deceptive action.

Movement Pattern Differences for Specified Body Parts

The present kinematic data demonstrate that distal body parts contain a rich source of information for discriminating deceptive from non-deceptive movements. Expertise research on action prediction has shown that the kinematic information provided by such distal body parts might have greater importance for predicting action intentions than other body parts (Abernethy, 1990; Ward et al., 2002; Williams, Huys, Cañal-Bruland, & Hagemann, 2009). This might be due to the fact that the strongest dissimilarities between movements are found in distal body regions. Our data show that the spatial dissimilarities between performed throws were the highest for left (nonthrowing) followed by right arm–hand regions and that they increased strongly when close to ball release. Consequently, distal body regions contain salient information and important effector attributions. The increase of spatial dissimilarities close to ball release might be due to some fundamental aspects of the kinematics having to differ in terms of the veracity of the action intentions when the movement phase gets closer to ball release (Lopes et al., 2014; Richardson & Johnston, 2005; Runeson & Frykholm, 1983).

However, it is surprising that distal parts of the nonthrowing arm show the highest spatial dissimilarity for both novice and expert performers in the present study. This effect might be due to the kinematic constraints of a deceptive movement such as the need for contralateral movements to prevent ball dropping or to maintain postural stability. Thus, movements of the nonthrowing arm and hand region absorb resulting forces of the effector-specific regions. Consequently, body parts of the throwing arm show only the second highest spatial dissimilarity. Indeed, these differences rely on the end effector that directly produces the action effect. Therefore, it can be stated that effector-specific as well as effector-unspecific spatial dissimilarities between deceptive and non-deceptive movements appear because of the biomechanical constraints on the present movement. This is an important point regarding the observation of movements performed by others. Expertise research on action prediction demonstrates that gaze is directed toward distal effector-specific body parts rather than toward other regions (e.g., Abernethy & Russell, 1987b; Alder, Ford, Causer, & Williams, 2014). Likewise, these parts control the manipulandum (e.g., the ball) and therefore contain salient information for the observer. However, our kinematic findings provide considerable evidence for the importance of effector-unspecific movement attributions while observing opponents' actions.

Implications for Real-Time Field Situations

The results also have implications for real-time field situations. Our linear analysis approach does not take into account whether differences in the kinematic patterns are potentially available at a point in time at which adaptations of the motor response would possibly be just in time or maybe too late. It has been proposed that the effective (because early) pick-up of kinematic information is an essential component for anticipating the action outcome of an opponent (Mueller & Abernethy, 2006; Mueller, Lalovic, Dempsey, Rosalie, & Harbaugh, 2014). The closer the information pick-up is to the event of ball release, the less time is available to initiate an effective motor reaction. In a handball-related RT paradigm, Helm, Reiser, and Munzert (2016) demonstrated that a four-choice response task already revealed a mean RT of about 280 ms. This task represents the basic task of a goalkeeper to defend the four corners of the goal. The ball flight duration in the present study averaged around 240 ms. Therefore, it can be argued that the decision for a response must be finalized before ball release. Our data reveal that the highest spatial dissimilarities between deceptive and non-deceptive throws occurred in the final movement phase (close to ball release). This effect has often been reported in the literature (Brault et al., 2010; Lopes et al., 2014). Thus, kinematic information available in the final movement phase is plausibly difficult to deploy when adapting one's own motor behavior to the observed action. Consequently, it might after all be argued that expert athletes are highly capable of disguising their action intentions when performing (effector-specific) deceptive movements (e.g., throwing).

Conclusion

The present data reveal that the linear classification of deceptive and non-deceptive effector-specific movements was performed more inaccurately for expert in comparison to novice athletes. The data from the dissimilarity analysis indicate that spatial dissimilarities between throws increased significantly over time. Further, the data show that the strongest spatial dissimilarities occurred for effector-unspecific body parts and close to ball release. Taken together, the findings suggest three main conclusions: first, effector-unspecific body parts contain important information for discriminating throws that might be a result of the biomechanical limitations to mimicking a genuine movement when performing a deception. Second, athletes are able to develop the necessary motor expertise to clearly disguise their deceptive action intentions when taking temporal limitations of real-time field situations into account. And third, expertise in performing movement deceptions depends mainly on keeping spatial dissimilarities small.

However, future perceptual research should directly address the question how the availability of information and changes in spatial (and/or temporal) dissimilarity influence the effectiveness of deceptive movements.

4 Perceptual Discriminability of Effector-Specific Deceptive and Non-Deceptive Movements: The Role of Spatiotemporal Dissimilarity and Response Time

This chapter reports a psychophysical experiment investigating the roles of spatiotemporal dissimilarity and response time distribution in the perceptual discriminability of deceptive and non-deceptive movements. It addressed this question in the context of 7-m penalty throws in team handball. Based on the motion capture data of the deceptive and non-deceptive penalty throws reported in chapter 3, realistic 3D motion avatars were generated as the experimental stimuli. Novice and expert handball field players were given a perceptual task asking them to judge as quickly and accurately as possible whether observed throws were either deceptive or non-deceptive. Results showed that both groups were highly sensitive to deception in throws when responses were given after stimulus offset. Expert observers were significantly better than novices at discriminating throws by both expert and novice penalty takers. In general, discriminability related directly to spatiotemporal dissimilarities between deceptive and non-deceptive throws. However, discriminability was impaired when responses were given prior to stimulus offset. Under these conditions, sensitivity to deception changed dramatically for both observer groups. Two possible lines of reasoning are proposed to explain this: first, early kinematic information in throws was not sufficient enough to discriminate; and second, observers did not have enough time to validate their decision.

4.1 Introduction

Human actors are extremely sensitive to other people's action intentions, and they recognize them quickly and efficiently from their movement kinematics (Blake & Shiffrar, 2007; Frith & Frith, 2006; Troje, 2008; Runeson & Frykholm, 1981; Zentgraf et al., 2011). This is even the case when people try to disguise their real action intentions in order to deceive others (Grèzes, Frith, & Passingham, 2004; Runeson & Frykholm, 1983). Psychologists have been studying deception for more than two decades. In early days, Runeson and Frykholm (1983) investigated the perceptual sensitivity for more object-directed deceptions such as disguising the weight of a lifted box. Their results demonstrated that observers were highly sensitive to deception—particularly as the deceived weight increased.

In recent years, expertise research in the sport science domain has provided a broad body of literature on how the human body is used as a deceptive tool (Brault et al., 2010; Lopes et al., 2014; Helm, Munzert, & Troje, 2016) and, more importantly, on how sensitive athletes are toward such deceptive intent (Cañal-Bruland & Schmidt, 2009; Cañal-Bruland et al., 2010; Jackson et al., 2006; Mori & Shimada, 2013; Rowe et al., 2009; Sebanz & Shiffrar, 2009). One major finding within this research is that expert observers outperform novices in recognizing deceptive action intentions on the basis of observed movement kinematics. Cañal-Bruland and Schmidt (2009) demonstrated this superior expertise performance for recognizing deceptive 7-m penalty throws in team handball. Their results showed that expert handball field players and goalkeepers could recognize the deceptive actions more accurately than novices. Similar effects have also been reported in other sports such as rugby (Brault et al., 2012; Jackson et al., 2009; Mori & Shimada, 2013), association football (Dicks et al., 2010a), basketball (Sebanz & Shiffrar, 2009), or tennis (Rowe et al., 2009). Nonetheless, most of these studies demonstrated that both novice and expert observers were more or less susceptible to deception.

In spite of these consistent findings, the majority of studies had two major limitations: first, researchers divided the stimuli they used into only two main categories: deceptive and non-deceptive actions; and they did this even when different deceptive and non-deceptive stimuli were used throughout the experiment. However, research has demonstrated that, for example, deceptive and non-deceptive movements typically display a different degree of spatial and/or temporal dissimilarity in their motion trajectories and temporal dynamics. Helm, Munzert, et al. (2016) demonstrated this for the spatial component of 7-m penalty throws in team handball. They showed that spatial dissimilarities differed not only between performer groups (novices vs. experts) but also across all participants as well as throughout the movement phase. Schorer et al. (2007) reported similar effects of inter- and intraindividual movement differences for non-deceptive penalty throws. Further, it has been demonstrated that the perceptual recognizability of over-exaggerated spatial movements (Pollick et al., 2001) and over-exaggerated temporal movements (Hill & Pollick, 2000) is higher the stronger the dissimilarities are between the exaggerated movement patterns and their grand average. Overall, these kinematic and perceptual findings indicate the importance of using more than just two stimulus categories, because the different kinematic patterns could have already influenced perceptual performance. Regarding the second limitation, specifically for tasks in which button presses are given as a response, participants were mainly instructed to give their judgments after stimulus presentation. Indeed, although participants were nearly always instructed to be as accurate and quick as possible, they were still not allowed to give responses prior to stimulus offset. However, when turning to applied contexts, in-situational paradigms indicate that observers will already start reacting before the action outcome itself becomes visible (Brault et al., 2012; Dicks et al., 2010a). The importance of giving an early response also becomes clearer in light of findings from RT experiments (Helm, Reiser, et al., 2016). The RT needed to process incoming information and initiate a motor response is often equal to or longer than the duration between the visibility of the action outcome and the achievement of the action goal (cf. Helm, Munzert, et al., 2016). Considering highly time-limited tasks such as one-on-one situations in sport, responses would simply occur too late if the prediction of the action intention (outcome) is made shortly before or at the moment when the action outcome itself becomes visible. Thus, it remains unclear how far previously reported perceptual skills in expert athletes actually are applicable to real-time field situations under temporal constraints.

Another major finding on deceptive action recognition and effect anticipation comes from temporal occlusion paradigms. These indicate that the amount of available information influences perceptual recognizability (Abernethy & Russell, 1987a, 1987b; Dicks et al., 2010a; Farrow, Abernethy, & Jackson, 2005; Jackson et al., 2006;

Mori & Shimada, 2013). The ability to accurately predict the action outcome of an observed action decreases as a function of temporal occlusion: the less kinematic information available, the worse the anticipatory performance. It has been shown that temporal occlusions influence the recognizability of deceptive actions more strongly than that of non-deceptive actions (Dicks et al., 2010a; Mori & Shimada, 2013; Rowe et al., 2009). Nevertheless, it is suggested that experts are generally less susceptible to deception, especially when only information close to the visibility of the action outcome is occluded (Abernethy & Russell, 1987a, 1987b; Farrow et al., 2005; Mori & Shimada, 2013). However, these anticipation skills are reported for tasks that lack temporal constraints—due either to their idiosyncratic demands or to the experimental instructions. Therefore, it might be concluded that expert athletes may potentially possess the ability to predict an action outcome based on a smaller amount of valuable kinematic information, but whether these skills are applicable to situations in which temporal limitations are necessary remains an open question.

The present study aims to investigate the influence of spatiotemporal dissimilarities and response time distributions on the perceptual discriminability of expert and novice observers. More specifically, it asks whether the amount of spatiotemporal dissimilarity between deceptive and non-deceptive 7-m penalty throws influences the perceptual discriminability of these effector-specific movements; and second, does the time of a given response influence this discriminability during an alternative forced-choice task. Further, it asks whether motor expertise actually does facilitate perceptual discriminability more strongly, and/or whether perceptual performance is less prone to failure in the case of quick responses. These questions were addressed in the context of 7-m penalty throws in team handball. A priori, it was predicted that, in general, perceptual discriminability would increase linearly as a function of spatiotemporal dissimilarity between deceptive and non-deceptive throws. However, it was hypothesized that this discriminability would become impaired if early responses were given. Regarding the benefits gained from motor expertise, it was predicted that perceptual discriminability in expert observers would be facilitated more strongly in the presence of only fewer dissimilarities between the movements, and that the impairment of discriminability in expert observers would be less marked than that in novice observers when early responses were given.

4.2 Methods

Participants

Forty male participants with normal or corrected-to-normal vision took part in this study (M_{age} = 24.5 years, *SD* = 3.2). Approval of the study was granted by the local ethics committee of the Justus-Liebig-University Giessen. All participants gave their informed written consent in accordance with the Declaration of Helsinki. Participants were divided into two groups: experts (competitive to successful elite team handball field players, classified according to Swann et al., 2015, *n* = 20) and novices with experience in recreational sports, but no other experience in team handball or goalkeeping (*n* = 20). Novices reported exercising an average of once a week in different sports such as association football, basketball, or fitness training. Team handball field players from the expert group reported practicing for an average of 10.5 hrs per week (*SD* = 4.5) and had a mean playing experience of 16.5 years (*SD* = 4.3).

Experimental Design and Movement Stimuli

In summary, I conducted an experiment presenting a total of 10 different realistic motion avatars performing 7-m penalty throws on a computer screen. These stimuli varied with respect to the amount of available spatial and temporal dissimilarity between the synthesized and averaged (non)deceptive throws. Stimuli were also categorized into two groups of penalty takers: experts (*n* = 5) and novices. By pressing a button, participants had to judge whether the observed throws were either deceptive or non-deceptive.

Test stimuli were produced from the database of 1,580 deceptive and non-deceptive 7-m penalty throws compiled by Helm, Munzert, et al. (2016). Based on their results obtained from an LDA, reconstructed averaged deceptive and non-deceptive throws were used to synthesize new patterns of penalty throws. Linear morphing between the averaged non-deceptive (ND) and deceptive (D) throws produced a set of five different stimuli by increasing the amount of spatiotemporal dissimilarity. This procedure was carried out separately for both expert and novice penalty takers (PT).

Note explicitly that the dissimilarity analysis between the deceptive and non-deceptive throws performed by Helm, Munzert, et al. (2016) revealed stronger dissimilarities for novice compared to expert PTs. This is also reflected in the newly synthesized throws. A detailed description of the linear computations is given in Figure 12. Based on the resulting motion data, body animations were reconstructed by means of MoSh (Loper, Mahmood, & Black , 2014). These realistic avatars were then generated in 2D at a resolution of 1920 × 1200 pixels using blender 2.76 (Blender Foundation, Amsterdam, NL). It is important to use this technique, because the, in the context of perceptual research often used point-light technique, provides some ambiguous information about motion in depth (Vanrie et al., 2004; Weech et al., 2014). Because this study investigated the perceptual recognizability of throwing movements, information about motion in depth could be highly relevant for perceptual performance. This is one major reason for using motion avatars as experimental stimuli.

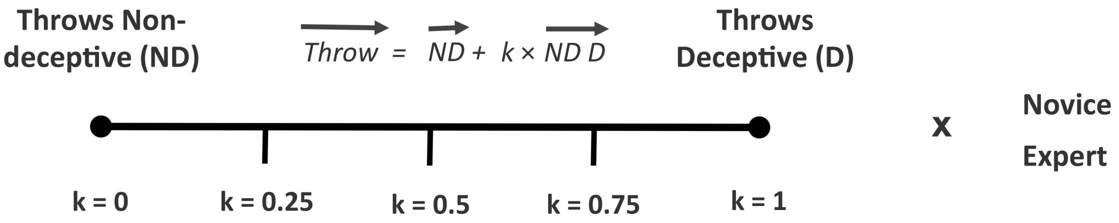

***Figure 12** | Description of stimulus computation. Details of the morphing procedure and the linear computation of the experimental stimuli*

Procedure and Perceptual Task

Prior to the experimental block, participants completed a short test during an introductory session to familiarize themselves with the experimental setting. They were seated with their eyes at approximately 65 cm from a two-dimensional screen (51.8 cm in the horizontal and 32.5 cm in the vertical plane) that was adjusted to each participant’s height. Participants were instructed to remain still during the experiment, but were not restrained by a chin rest or bite bar. They looked at the on-screen stimuli and were not given instructions regarding where to fixate. Participants rated a total of 300 penalty throws by pressing buttons on a response time box. After each block of 50 trials, participants rested for 1.25 min before continuing the experiment. They were instructed to judge whether the observed penalty throw was either deceptive or non-deceptive, and to do this as accurately and quickly as possible. Responses could already be given during stimulus presentation. All trials started with a blank screen that was displayed for 2s, and followed by a picture of the first frame of the motion avatar that was frozen for a duration of 0.5–1.0 s. Subsequently, the avatar started to move and performed a penalty throw until the event of ball release or predicted ball release in the deceptive trials. After this event the avatar became occluded and 240 ms later a beep was caused to sound in order to force participants in responding quickly. Stimulus duration ranged between 620–880 ms. An illustration for the overall trial structure is given in Figure 13.

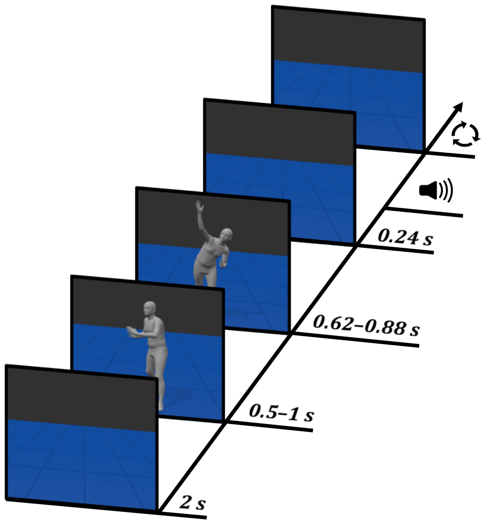

Figure 13 | *Trial structure. Temporal characteristics of all motion stimuli.*

Data Analysis

The proportion of perceived deceptive trials (PPD) and response times (RPT)—defined as the time between stimulus onset and pressing the response button—were calculated using MATLAB R2015b (MathWorks, Natick, MA, USA). Due to the differences in stimulus duration, the RPT values were aligned to the stimulus offset that then equaled the RPT of zero in all conditions. As a result, negative RPT values indicated a button press prior to stimulus offset, whereas positive values indicated a button press after stimulus offset. Subsequently, RPT were inspected and absolute cutoffs were used for data correction. Trials outside the interval *minus length of stimulus/2* < RPT < 480 ms (3.9%) were discarded from the data analysis. PPD were analyzed separately for responses given prior to stimulus offset (*early RPT*) and responses given after stimulus offset (*late RPT*). In order to test our hypothesis of a linear relationship between the perceptual discriminability and the amount of available spatiotemporal dissimilarity between throws, a simple linear regression model, using least-squares estimation was applied to our perception scores (PPD). Further analysis was mainly concentrated on the slopes obtained from the regression lines which were interpreted as a measure of perceptual discriminability. Coefficients of determination (r^2) were calculated for the linear regression models obtained from the averaged PPD scores to control the goodness of fit. To further assess the participant's response behavior, the intercepts of the averaged linear regression lines were calculated and interpreted as a measure of response bias. To test any effect of observer group on the overall RPT distribution, the ex-Gaussian PDF was fitted to each participant's RPT data, and the characteristics of the whole distributions were analyzed. As already mentioned in chapter 2, the ex-Gaussian PDF is described by three parameters: μ (*mu*), the mean of the Gaussian distributed part, σ (*sigma*), the standard deviation of this part, and τ (*tau*), the mean of the exponential part that characterizes the skewness of the overall distribution (Burbeck & Luce, 1982; Lacouture & Cousineau, 2008) indicating the proportion of excessively slower response times (see Helm, Reiser, et al., 2016, for more details).

Statistics

Perception scores. Separate 2 (Observed throw: expert PT vs. novice PT) × 2 (Observer group: experts vs. novices) ANOVAs with repeated measures for the comparison of individual differences between observed throws were used to determine the effects for slopes of the linear regression lines. ANOVAs were separately performed for the slopes in *early* and *late RPT*. *Post hoc*, multiple pairwise comparisons were conducted to determine the locus of significant differences of given responses (*early vs. late*) for slopes separated by groups. Bonferroni corrections were made to control the family error rate.

Response time distributions. Multiple independent-samples *t* tests were used to determine the effects of overall response time distributions for the parameters of the ex-Gaussian PDF between groups.

4.3 Results

Perception Scores

Figures 14/15 illustrate the results on the participants' perceptual performance separately for *early* and *late RPT*. Overall, the averaged PPD scores as well as the plotted linear regression lines suggest that slopes were generally smaller for the early in comparison to the late judgments, indicating an impairment of perceptual discriminability. Intercepts of the linear regression lines were generally higher for the observed novice (*late RPT:* > 0.16; *early RPT:* > 0.41) in comparison to the expert (*late RPT:* < 0.10; *early RPT:* < 0.23) PT. Statistical results of the four separate 2 (Observed throw: expert PT vs. novice PT) × 2 (Observer group: experts vs. novices) ANOVAs for slopes of the linear regression lines in *early* and *late RPT* are reported in

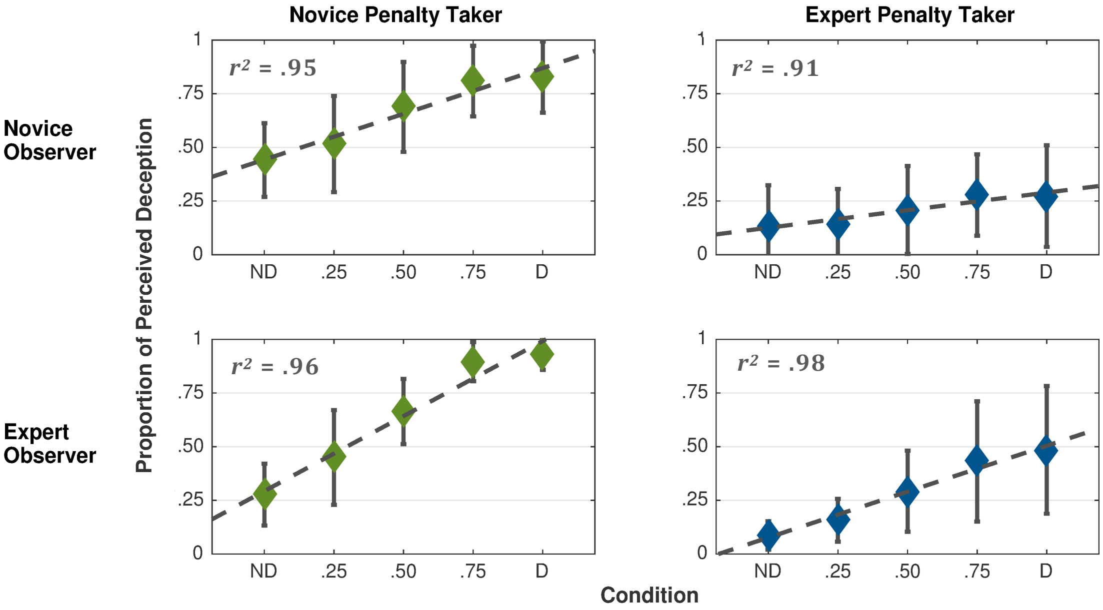

Figure 14 | *Perception scores of late RPT. The proportion of perceived deception (PPD) is illustrated separately for observer group (novice vs. expert) and for observed penalty taker (novice vs. expert). Error bars represent SD of the group mean. Dashed lines represent linear regression lines.*

Table 6. The important effects of slopes are demonstrated by a significant main effect for Group in *late RPT*, $F(1, 38) = 13.87$, $p = 0.001$, $\eta_{\rho}^2 = 0.267$, with, on average, higher slopes for the expert observer group. In comparison, the main effect for Group in *early RPT* failed to attain significance, $F(1, 38) = 1.0$, *ns*. These effects indicated that expert observers were significantly better than novices in recognizing action intentions only when responses were given after stimulus offset. The analyses also revealed significant main effects for Observed throw in *early* as well as *late RPT* (*early*: $F[1, 38] = 6.84$, $p = 0.013$, $\eta_{\rho}^2 = 0.152$; *late*: $F[1, 38] = 44.25$, $p < 0.001$, $\eta_{\rho}^2 = 0.538$) with higher slopes when novice PT were observed. Post hoc multiple pairwise comparisons between slopes of the expert observer group in the *early* versus *late RPT* revealed significant differences for observing only the expert (*early RPT* vs. *late RPT*: $t[19] = 2.57$, $p = 0.019$) but not for the novice (*early RPT* vs. *late RPT*: $t[19] = 0.33$, *ns*) PT. Differences between slopes of the novice observer group in the *early* and *late RPT* did not attain significance at all, $t(19) < 1.61$, *ns*. However, coefficients of determination (r^2), listed in Figure 14/15 indicate that the goodness of fit for the linear regression model decreased dramatically for the early PPD scores.

Table 6 | *Results obtained from the linear regression analysis. Averaged slopes as well as statistical results of within-subject and between-group effects are reported separately for early and late RPT.*

	Expert Observer (n = 20)		Novice Observer (n = 20)				
	Expert PT mean (*SD*) in units	Novice PT mean (*SD*) in units	Expert PT mean (*SD*) in units	Novice PT mean (*SD*) in units	Cond *F (p value)*	Group *F (p value)*	Cond x Group *F (p value)*
Early RPT	.0188 (.15)	.1540 (.28)	.0231 (.08)	.0685 (.09)	6.84 $^{(*)}$	1.0 $^{(ns)}$	1.69 $^{(ns)}$
Late RPT	.1067 (.08)	.1745 (.06)	.0400 (.05)	.1060 (.06)	44.25 $^{(***)}$	13.87 $^{(**)}$	.008 $^{(ns)}$

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

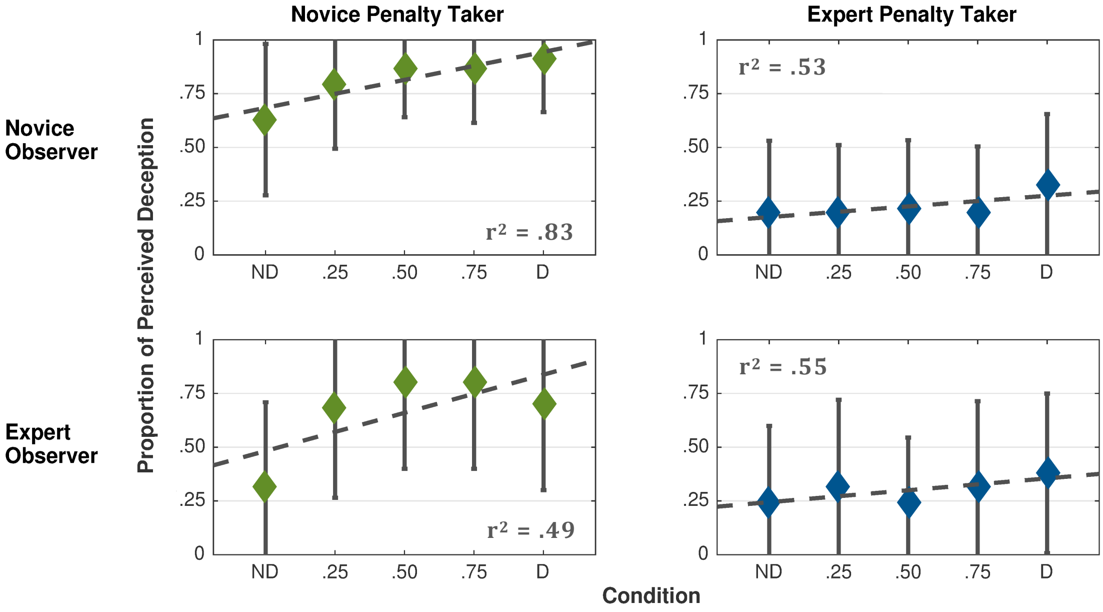

Figure 15 *| Perception scores for early RPT. The proportion of perceived deception (PPD) is illustrated separately for observer group (novice vs. expert) and for observed penalty taker (novice vs. expert). Error bars represent SD of the group mean. Dashed lines represent linear regression lines.*

Response Time Distributions

The ex-Gaussian PDFs for the overall RPT distribution of the novice and expert observers are illustrated in Figure 16. The independent-samples *t* tests revealed a significant difference between groups only for the parameter μ, $t(38) = 2.77$, $p < 0.01$, but not for parameters σ, and τ, $t(38) < 0.27$, *ns*. This indicates that novice observers tended to respond more quickly than their expert counterparts.

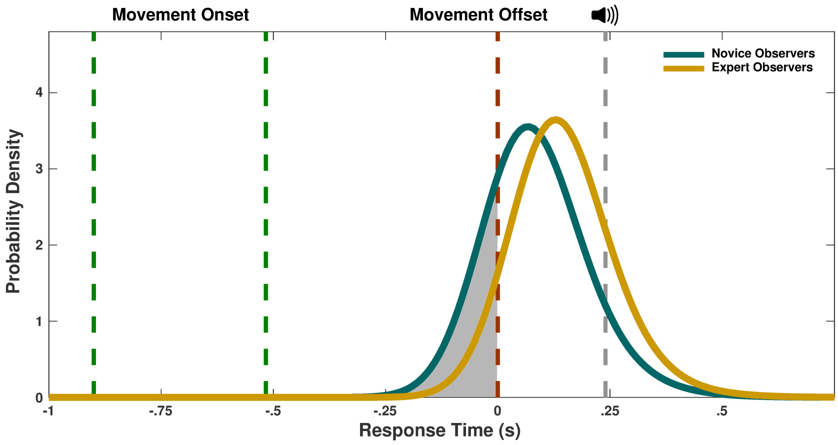

Figure 16 *| Response time distributions. Ex-Gaussian PDFs are shown for the response times of novice and expert observers.*

4.4 Discussion

The present study investigated the effects of spatiotemporal dissimilarity and response time distributions on the perceptual discriminability between deceptive and non-deceptive throwing. This was addressed in the context of 7-m penalty throws in team handball. Expert and novice observers judged as accurately and quickly as possible whether observed throws were either deceptive or non-deceptive. In general, results replicate findings showing a superior expertise performance for discriminating deceptive from non-deceptive movements based on its kinematics when judgments were given after stimulus offset (Brault et al., 2012; Cañal-Bruland & Schmidt, 2009; Sebanz & Shiffrar, 2009). However, these findings were extended by showing that the perceptual discriminability increased as a function of spatiotemporal dissimilarity; and that these effects do not exist for judgments in which responses were given prior to stimulus offset. The present data lead us to suggest that the expertise superior performance in recognizing deceptive action intentions based on the movement kinematics could decrease under temporal constraints. The following sections will discuss the main findings and their implications for real-time field situations in more detail.

Perceptual Discriminability of Deceptive and Non-Deceptive Movements

Anticipating other people's action intentions is not just an important skill in daily life. It is also an essential part of successful perceptual-motor performance in one-on-one situations in the sport domain. Expertise research in that domain has demonstrated that expert athletes are highly capable of recognizing the intentions underlying deceptive and/or non-deceptive movements (Brault et al., 2012; Cañal-Bruland & Schmidt, 2009; Jackson et al., 2006; Mori & Shimada, 2013; Sebanz & Shiffrar, 2009). The main argument is that experts are better than novices at recognizing the action intentions of an opponent based on the available movement kinematics. However, these findings are limited due to the lack of temporal constraints on the perceptual judgment tasks. The present data help to overcome these limitations, and extend previous findings with respect to the role of spatiotemporal dissimilarity and response time distributions.

The role of spatiotemporal dissimilarity. In recent years, a number of behavioral experiments have focused on analyzing deceptive and/or non-deceptive movement kinematics (Brault et al., 2010; Helm, Munzert, et al., 2016; Lopes et al., 2014; Schorer et al., 2007). Independent from their idiosyncratic findings, all these experiments showed similar effects of inter- and intraindividual movement differences. However, these substantial characteristics were not taken into account when investigating and analyzing the perceptual performance of recognizing deceptive and non-deceptive actions (cf. Cañal-Bruland & Schmidt, 2009; Jackson et al., 2006; Rowe et al., 2009; Sebanz & Shiffrar, 2009). For the first time, the present data demonstrate that the amount of available dissimilarity between different types of movements influences the perceptual discriminability of deceptive and non-deceptive penalty throws in team handball. Slopes of the regression lines in the *late RPT* of the expert and novice observers suggest that the perceptual discriminability between deceptive and non-deceptive penalty throws increases linearly as a function of spatiotemporal dissimilarity. The assumption of a linear relationship is validated by the coefficients of determination for the linear model ($r^2 > .91$). This indicates that the linear regression model provides a reliable estimation of the relationship between the perceptual discriminability and the amount of available dissimilarities between throws. Further, both novice and expert observers are generally better at discriminating throws by the novice in comparison to the expert penalty taker—independent from the time of the given response. This can also be explained by the fact that the dissimilarities between novice throws were significantly higher than those between expert throws (cf. Helm, Munzert, et al., 2016). One possible explanation for this relationship goes back to the theories of action simulation (Jeannerod, 2001; Zentgraf, Munzert, Bischoff, & Newman-Norlund, 2011) and internal modeling (Blakemoore & Decety, 2001; Shmuelof & Zohary, 2007). In this context, a central assumption is that action observation activates internal representations of the observer's motor system that let the observer simulate the movement behavior internally (Jeannerod, 2001; Zentgraf et al., 2011). Consequently, this simulation enables the observer to infer the action goal and predict the future action outcome by means of internal forward models (Blakemoore & Decety, 2001; Shmuelof & Zohary, 2007). On these grounds, it is suggested that stronger dissimilarities facilitate perceptual recognizability, because matching the perceived motion patterns against the internal motor representations of the deceptive (non-deceptive) movements might produce a more distinct classification. Accordingly, this could result in a more distinct perceptual discriminability. This assumption is also supported by findings reported by Hill and Pollick (2000) as well as Pollick et al. (2001) demonstrating that the perceptual recognizability of observed movements increases as a function of over-exaggerating the spatial and/or temporal cues in movements.

Regarding the inconsistent findings on the observers' susceptibility to deception, our data also help to demonstrate that expert observers are more or less susceptible to deception depending on the available spatiotemporal dissimilarities. This could be one possible reason why the literature reports what is sometimes a stronger or a weaker impairment in recognizing deceptive in comparison to non-deceptive movements (Cañal-Bruland & Schmidt, 2009; Dicks et al., 2010a; Jackson et al., 2006; Rowe et al., 2009; Sebanz & Shiffrar, 2009).

The role of response times. As mentioned above, there is plentiful evidence for superior expert performance in predicting the outcome of an observed action. Again, the present data replicate these findings in the context of discriminating between more or less deceptive and non-deceptive 7-m penalty throws in team handball. Judgments of the late responses demonstrate that expert observers are significantly better than novices at discriminating throws by both the expert and novice penalty taker. The relationship between the accuracy of the perceptual judgments and late responses suggests that observers predominantly take their time when accurately predicting the action outcome of the observed throws. However, taking the results on the perceptual judgments of early responses into account, it is generally demonstrated that recognizability becomes impaired when responding early. In particular, the statistical results demonstrate that expert observers' perceptual discriminability for throws by expert penalty takers decreases significantly when perceptual judgments are given prior to stimulus offset. In contrast, perceptual discriminability in expert observers for novice penalty takers as well as perceptual discriminability in novice observers for novice and expert penalty takers does not decrease significantly when judgments are given early. However, on closer consideration, the differences in response biases between the early and late RPT condition point to a general shift in response behavior. In general, participants are more strongly biased to judge throws as deceptive in the early RPT, and further, this bias becomes even stronger when observing the novice PT.

Two possible lines of reasoning are proposed for these effects and, in particular, for the changes in perceptual discriminability: first, the early perceptual judgments of expert observers might have been made on the basis of insufficient or misleading kinematic information. Indeed, it has been demonstrated that dissimilarities between deceptive and non-deceptive movements become strongest close to or at the moment when the action outcome becomes visible (Brault et al., 2010; Helm, Munzert, et al., 2016; Lopes et al., 2014). Further, dissimilarities during the early movement phase might not have been strong enough to discriminate between throws. During that movement phase, it can be assumed that expert penalty takers are highly capable of mimicking the kinematic cues of non-deceptive throws. The shift in response biases in the early RPT condition provides some evidence for uncertainty in the observers' response behavior when judging expert PT. In general, non-deceptive throws are viewed more frequently as deceptive. This first line of reasoning is also supported by findings taken from temporal occlusion paradigms demonstrating that perceptual performance decreases for very early occlusion points. This is suggested to be due to a lack of sufficient information for the action recognition and effect anticipation (Abernethy & Russell, 1987; Farrow et al., 2005; Mori & Shimada, 2013; Rowe et al., 2009). However, research in that domain has also shown that (expert) observers are able to predict the action outcome with reduced kinematic information. Nonetheless, these findings come from experimental tasks that allowed participants an unlimited amount of time to make their perceptual judgments.

The second line of reasoning focuses more on the temporal limitations of the early responses. In order to produce a reaction in a one-on-one situation in sport, for example, several perceptual-cognitive and (pre-)motor processes are required to achieve an appropriate action goal. Selecting the correct response can be a complex and temporally extended process (Araújo, Davids, & Hristovski, 2006). Especially in situations in which ambiguous kinematic information might produce indistinct movement classifications, it seems to be necessary to evaluate the response selection. However, additional time is needed for this process. In the case of temporal limitations, it is hard to carry out such an adequate response evaluation. This dramatically increases the possibility of incorrect responses or guesses.

In sum, I suggest that the decrease in perceptual recognizability for expert observers is due to both a lack of sufficient information and/or temporal limitations on selecting and validating responses.

With respect to the overall differences in RPT distributions, the data reveal a significant effect between groups for the parameter μ. They show higher values for novice in comparison to expert observers. This indicates that novice observers tend averagely to respond more quickly than their expert counterparts. Because the distributions between groups do not differ significantly in parameter τ, both observer groups may equally tend to produce very slow responses with respect to the Gaussian distributed group mean. Overall, these findings are in line with research demonstrating that expert athletes wait longer to respond in order to minimize prediction errors when performing in domain-specific environments (Brault et al., 2012; Dessing & Craig, 2010). Further, the reported effect could also be a result of task difficulty. Considering the novices' perceptual discriminability when observing expert PT, it could also be that this task is simply too difficult for the novices, and this then results in quicker response behavior for that condition.

Practical implications. Considering findings from RT experiments in team handball as well as the temporal constraints of real-time field situations, it is suggested that perceptual judgments based on movement kinematics must be made prior to the visibility of the action outcome (i.e., ball release) when effectively saving a 7-m penalty throw. Otherwise, goalkeepers will not have enough time to defend the goal successfully. For instance, in a handball-related RT task, Helm, Reiser et al. (2016) reported that the RT on a four-choice response task averaged around 280 ms, whereas the ball flight duration during the 7-m penalty throws analyzed in Helm, Munzert, et al. (2016) revealed a mean duration of only 240 ms. Taking all this into consideration, it can be assumed that expert observers will not be able to discriminate between deceptive and non-deceptive 7-m penalty throws in an applied real-time field situation when relying on only the observed movement kinematics. Other, more contextual cues might also play an important role when information on the movement kinematics are ambiguous (cf. Cañal-Bruland & Mann, 2015).

Conclusion

The present data reveal that expert observers are significantly better than novices at discriminating throws performed by both an expert and novice penalty taker. Perceptual discriminability increases as a result of stronger spatiotemporal dissimilarity between the different throws. However, the data also demonstrate that the experts' superior performance in discriminating throws disappears when perceptual judgments are made prior to stimulus offset. Taken together, the findings suggest two main conclusions: first, the perceptual discriminability between deceptive and non-deceptive effector-specific movements increases as a function of spatiotemporal dissimilarity. This might be a result of fewer prediction errors resulting from the internal simulation of kinematically dissimilar deceptive and non-deceptive throws. Second, perceptual recognizability decreases as a function of early response time distributions due to a lack of sufficient kinematic information. Turning to the embedding of these findings in an applied context, I conclude that in situations in which observed movement kinematics appear to be ambiguous, expert athletes might also rely on other, for example, contextual information when discriminating deceptive from non-deceptive movements.

5 Conclusion and Outlook

5.1 Summary

In the last decade, research has focused increasingly on movement deception. Much is already known about the different facets of perceptual-cognitive processes, but less about the execution of the movement deceptions themselves. Indeed, some important questions are still unanswered. For example, what are the kinematic characteristics of more effector-specific deceptions, and how do spatial and/or temporal changes to the kinematic pattern influence the perceptual recognizability of these deceptions? Further, it is unknown how processing speed (response time) affects the recognizability in a forced judgment task, or how motor expertise (training) modulates the speed of internal processing. This dissertation has tackled these major questions.

The first experiment presented here demonstrated that motor expertise with its associated internal representations facilitates the perceptual-motor processing of domain-specific S–R tasks in a simple RT as well as in a double-response paradigm. Results also provide a clear picture of response time distributions for domain-specific tasks that helps to link together the execution and perception of effector-specific movement deceptions.

In the second experiment, I first characterized the kinematic features of effector-specific movement deceptions. Results showed that (a) deceptive and non-deceptive movements separate kinematically, (b) effector-unspecific body regions provide the highest dissimilarities between movements, and (c) expertise in performing deceptive movements depends mainly on the ability to mimic the spatial features of the corresponding non-deceptive movements. Second, the movement database could have been used to develop a new approach for synthesizing new movement patterns by controlling the spatial and temporal attributes. This was based particularly on the computation of linear classifiers between the deceptive and non-deceptive movements.

The third study reported in this dissertation used this approach to investigate the perceptual discriminability between deceptive and non-deceptive movements. Different deceptive and non-deceptive movements were synthesized to show, on the one hand, that perceptual discriminability increases as a function of spatiotemporal dissimilarity between movements, but, on the other hand, however, that this discriminability becomes impaired when judgments are given before the moment when the action outcome itself becomes visible.

5.2 Embedment in Previous Research

5.2.1 Characteristics of Movement Deceptions

In recent years, little attention has been given to research on the kinematic analysis of deceptive and non-deceptive movements. However, for a better understanding of the processes underlying the anticipation of deceptive action intentions, it is helpful to study the nature of the observable movement kinematics. In this context, seminal work on the kinematic features of whole-body movement deceptions demonstrated that the consistent balance between exaggerating and minimizing kinematic cues is a major attribute when performing whole-body movement deceptions (Brault et al., 2010; Lopes et al., 2014). In particular, the study by Brault et al. (2010) observed the most significant changes of the movement kinematics in the upper trunk, whereas kinematics of the lower trunk were minimized. This has not been replicated in the context of more effector-specific movement deceptions that were analyzed in the second study reported here. In detail, it has been shown that expert performers generally tried to minimize dissimilarities between the deceptive and corresponding non-deceptive movements when trying to deceive. It can be assumed that these differences in movement execution between the two types of deceptions are due to the different nature of the deceptions themselves. However, both types of movement deception illustrate the importance of manipulating kinematic cues in order to trigger misperception in the observer.

With respect to the principle of the non-substitutability of genuine actions reported for whole-body deceptions (Brault et al., 2010; Jackson et al., 2006; Lopes et al., 2014), the results of the LDA in the second study confirmed that this principle can be viewed as a general attribute when performing movement deceptions. Further, the data from the dissimilarity analysis also demonstrated that the non-substitutability effect increases the closer the movement phase comes to the moment when the action outcome becomes visible, and this is particularly the case in effector-unspecific body regions.

All in all, both whole-body and effector-specific movement deceptions are linked to some global characteristics in the kinematic pattern. This is described by the principle of the non-substitutability of genuine action. When trying to perform a deceptive movement, it might be possible to create some of the kinematic details of the corresponding non-deceptive movements, but not all the full details required to convince an observer that this movement is non-deceptive (Richardson & Johnston, 2005; Runeson & Frykholm, 1983, 1986). In the case of effector-specific deceptions, in particular, this is linked to effector-unspecific body regions. Notwithstanding, in its core, the two different types of movement deception differ essentially. On the one hand, a whole-body movement deception succeeds in providing a consistent balance between misleading and genuine information by exaggerating kinematic cues (e.g., in the upper trunk) in order to deceive while minimizing kinematic cues linked to body reorientation (e.g., in the lower trunk) in order to disguise (Brault et al., 2010). On the other hand, expertise in performing effector-specific movement deceptions is characterized by mimicking non-deceptive movements to disguise the deceptive intent; and that is achieved by keeping spatial dissimilarities to non-deceptive movements as small as possible.

In addition, the literature suggests that the execution of deceptive actions changes the observer's perceptual mode of functioning (Jackson et al., 2006; Smeeton & Williams, 2012). It is suggested that changes (e.g., exaggeration) of local advance cues in deceptive movements alter the mode of functioning from an invariant (holistic) to a more cue-based (inferential) mode. Because effector-specific deceptions are potentially a kind of movement mimicry that involves the (optimal) reproduction of non-deceptive movement patterns, I would cautiously suggest that this type of movement deception would tend not to modulate a change in the perceptual functioning mode.

5.2.2 Perception of Movement Deceptions

Making assumptions about the action intentions of an opponent's movements based on their kinematics is a major source of information in the context of deceptive action recognition and effect anticipation. Much is known about the different facets of recognizing deceptive intent in movements (Cañal-Bruland et al., 2010; Jackson et al., 2006; Mori & Shimada, 2013; Sebanz & Shiffrar, 2009). Considering that past research often used domain-unspecific or superficial designs in the laboratory without any fundamental kinematic analysis of the stimuli being used, some questions remained unanswered. For example, how do spatial and/or temporal changes in the deceptive movement patterns influence perceptual recognizability? This question was tackled with the psychophysical experiment in the third study of this dissertation by means of the synthesis approach taken from the second study. The results demonstrated that the perceptual discriminability between deceptive and non-deceptive movements increases linearly as a function of spatiotemporal dissimilarities between movements. This complements findings on action recognition showing that the over-exaggeration of spatial (Pollick et al., 2001) and/or temporal (Hill & Pollick, 2000) attributes of the movement kinematics facilitates the perceptual recognizability of non-deceptive actions. The principle of the kinematic specification of dynamics (Runeson, 1977; Runeson & Frykholm, 1983) can help to explain these effects. Supported by Pollick et al. (2001), it can be assumed that the increase in spatiotemporal dissimilarities (changes in the kinematic properties) covaries with the relevant dynamic properties. This then results in a more distinct action recognition and anticipation of the underlying action intent. Theories of action simulation (Jeannerod, 2001; Zentgraf et al., 2011) and internal forward modeling (Blakemoore & Decety, 2001; Shmuelof & Zohary, 2007) can further help to explain this effect from a more neurophysiological perspective. In this context, matching the perceived movements against the internal representation of corresponding deceptive (or non-deceptive) movements might result in a more distinct discrimination when the proportion of deceptive (or non-deceptive) cues in the observed movements are increased or more strongly represent the deceptive (non-deceptive) movement pattern. This would then facilitate the anticipation of the intended action effect.

As illustrated in section 1.3 of this dissertation, on the field, athletes are required to process information in a time-constrained environment. This could limit their ability to make use of kinematic information when anticipating deceptive action intents. Most previous research on movement deception did not take this into account (Cañal-Bruland & Schmidt, 2009; Jackson et al., 2006; Rowe et al., 2009; Sebanz & Shiffrar, 2009), because, for example, these studies concentrated on investigating other, more fundamental aspects underlying the recognition or effect anticipation of deceptive actions. In fact, the psychophysical results of the third experiment reported in this dissertation help to illustrate the role of response-time distribution in perceptual judgments of deceptive movements. The discrete analysis of the perception scores for responses given after stimulus offset (late) and for response given prior to stimulus offset (early) reveals that the attempt to give a quick response resulted significantly more often in a prediction error. This let me suggest that the early perceptual judgments were made on the basis of insufficient kinematic information. Indeed, the results of the second experiment in this dissertation indicate that performers were highly capable of disguising their action intentions by keeping dissimilarities in the earlier movement phase small. And that is what might have produced the lack of sufficient information for the action recognition. Similar results are reported in the context of temporal occlusion paradigms in which sufficient information becomes continuously more occluded resulting in an impaired action recognition or effect anticipation (Dicks et al., 2010a; Mori & Shimada, 2013; Rowe et al., 2009). Against this background, I assume that other, more contextual cues (e.g., situational probabilities) are additionally used to facilitate the perceptual recognizability of deceptive movements in the case of available ambiguous kinematic information. This notion is supported by research demonstrating the use of various sources of information when fast judgments are required in the presence of uncertainty (De Oliveira et al., 2014; Raab, 2012).

With respect to the speed of internal processing, the RT data from the first experiment in this dissertation showed that motor expertise facilitates the perceptual-motor processing of domain-specific responses. For many years, it has been argued that fast reactions are grounded in an advantage regarding action anticipation (see Mueller & Abernethy, 2012; Williams et al., 2011, for overviews), but for the first time, the RT data reported here help to broaden this assumption in a way that also considers that fast reactions are due to a facilitated internal perceptual-motor processing. This facilitation also holds for the “reprogramming of movements” that is suggested to be of importance in the context of processing deceptive actions. Taking this together with the results of the early responses given in the psychophysical experiment, I would draw the following conclusion for the recognition of deceptive action intents: facilitated internal perceptual-motor processing as well as action anticipation could produce quick responses, but if the prediction of future action outcomes is based on insufficient kinematic information, the overall performance is still a challenge. This supports the earlier notion that athletes have to make use of various information in the context of action recognition and effect anticipation on the field.

5.2.3 Linking Together the Execution and Perception of Movement Deceptions

The previous two sections discussed both the characteristics and the effects of performing effector-specific movement deceptions on perception. However, one major purpose of this dissertation is to contribute to a broader understanding of how the execution and perception of effector-specific movement deceptions are linked together. As mentioned above, a fundamental attribute of executing movement deceptions relies on a performer being able to mimic some of the kinematic features of corresponding non-deceptive movements, but not mimicking all of their full details (Jackson et al., 2006; Richardson & Johnston, 2005, Runeson & Frykholm, 1983, 1986). This is particularly true the closer the movement phase comes to the moment when the action outcome becomes visible (Lopes et al., 2014; see also section 3.3/3.4). These characteristics are thought to modulate an observer's perceptual recognizability, because observable differences between deceptive and non-deceptive movement kinematics might help to facilitate perceptual discriminability. However, considering the domain-specific RT reported in the first study of this dissertation, it becomes clear that athletes need to anticipate the action outcome significantly earlier before the action outcome itself becomes visible. In sum, the RT needed in a domain-specific task is longer than the duration between the visibility of the action outcome and the attainment of the action goal in a real-time field situation. As a consequence, I would then suggest that the non-substitutability of genuine actions would not help to facilitate the process of action recognition or effect anticipation, because distinct differences in the kinematic pattern between the deceptive and non-deceptive movements would appear too late to be made use of. Indeed, the results of the psychophysical study reported here provided clear evidence suggesting that the recognition of effector-specific movement deceptions becomes a challenge only when making use of early kinematic information under temporal constraints. Thus, this lets me suggest, however, that experienced performers are highly capable of disguising their deceptive action intent in real-time field situations.

5.3 Implications for Future Research

The results of the third study presented in this dissertation clearly support the notion that the perceptual recognizability of deceptive movements becomes a challenge under temporal constraints. This is thought to be due to the presence of ambiguous kinematic information provided by the performer. Because athletes, however, demonstrate exceptional skills of action recognition and effect anticipation on the field, it can be assumed that other, more contextual cues (e.g., situational probabilities) facilitate anticipatory performance under temporal constraints. The linear approach developed here of synthesizing new patterns of deceptive and/or non-deceptive movements could be a useful tool with which to investigate the fundamental principles and specific dependencies of making use of both kinematic and contextual (e.g., probabilistic) information as a function of the number of ambiguous kinematic cues available. This could help to broaden our understanding of action recognition and effect anticipation in the context of uncertainty under temporal constraints.

Likewise, in the third experiment of this dissertation, the impairment of perceptual recognizability in early responses was explained as being due to a lack of sufficient information. Based on the theories of action simulation (Jeannerod, 2001; Zentgraf et al., 2011) and internal modeling (Blakemoore & Decety, 2001; Shmuelof & Zohary, 2007), I argued that stronger dissimilarities between movements facilitate perceptual recognizability, because matching the perceived motion patterns against the internal motor representations of deceptive (non-deceptive) movements produces a more distinct classification. However, this is simply an assumption taken from previous research on that topic. With the new approach to synthesizing new movement patterns, it is possible to manipulate the spatial and temporal components of the movement kinematics as demonstrated in the psychophysical study of this dissertation. This could also help to answer several questions regarding the neurophysiological aspects of movement discrimination—particularly in the sense of deceptive intent. Up to now, little is known about the neural correlates underlying the recognition of deceptive action intentions (Bishop, Wright, Jackson, & Abernethy, 2013; Wright, Bishop, Jackson, & Abernethy, 2013). In this context, multivariate analysis approaches combined with the linear approach to synthesizing new movements would help to gain a better understanding of the neurophysiological mechanisms underlying the recognition of deceptive intents.

As a last point, one aspect that stands out in the work presented here is the effort in designing highly domain-specific experimental tasks. Most research in the last 20 years has used superficial paradigms in the laboratory rather than more naturalistic settings to investigate the execution and perception of movement deceptions. However, in recent years, a handful of studies has taken this into account by making use of virtual reality (e.g., Brault et al., 2012; Craig, 2014; Vignais et al., 2015). Research on deception and action prediction in general could benefit from the use of virtual reality setups, because they would allow a closer link between movement execution and perception—particularly in the context of, for example, the field player versus goalkeeper interaction in sports.

6 References

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Erklärung

Ich erkläre: Ich habe die vorgelegte Dissertation selbstständig und ohne unerlaubte fremde Hilfe und nur mit den Hilfen angefertigt, die ich in der Dissertation angegeben habe. Alle Textstellen, die wörtlich oder sinngemäß aus veröffentlichen Schriften entnommen sind, und alle Angaben, die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht. Bei den von mir durchgeführten und in der Dissertation erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der "Satzung der Justus-Liebig-Universität Gießen zur Sicherung guter wissenschaftlicher Praxis" niedergelegt sind, eingehalten.

Gießen, 29. September 2016

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Fabian Helm