UNIVERSIDADE TÉCNICA DE LISBOA
FACULDADE DE MOTRICIDADE HUMANA

# Decision-making in the Penalty Kick: the Role of Constraints in the Perceptual Guidance of Action

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## Abstract

The aim of this thesis was to examine how players' strategies influence available information on movement when performing penalty kicks. An ecological dynamics perspective of the penalty kick is initially presented as a supporting framework for recent research, as well as a plausible path to overcome the shortage of ecological validity of experimental designs that aim to capture the information-based core of players' performance. The effect of different instructional constraints on movement patterns and outcome was analysed and results showed a significant influence on both players' performance speed and on goalkeepers' diving angle, although players' efficacy remained constant. Penalty takers' kinematics was then studied in order to understand its relation with ball's horizontal and vertical directions, as well as the influence of ball direction on penalty kicks' success. Kinematic variables highly correlated to ball horizontal direction were less affected by deceptive actions, demonstrating that genuine movements cannot be biased if an intended goal needs to be accomplished. Ball height influenced outcome, although physical constraints imposed on penalty takers' movement variability (compared with other kick types) decreased the correlations between ball's vertical direction and penalty takers' kinematics. Developed investigation contributed to 1) clarify the influence of different strategies on players' movements, 2) identify genuine sources of information for the anticipation of ball direction, and 3) determine the influence of ball height on penalty kick success.

**Keywords**: penalty kick, decision-making, perception-action, instructional constraints, strategy, distributed information, local information, kinematics, predictive information, ball direction.

## Resumo:

Esta tese tem como objectivo analisar a influência das estratégias empregues pelos jogadores sobre a informação disponível para a acção na grande penalidade. A dinâmica ecológica é apresentada como base para o enquadramento da pesquisa recente, e como opção plausível para potenciar a validade ecológica dos designs experimentais que pretendam capturar a informação sobre a qual os jogadores agem. Foi analisado o efeito da instrução sobre o comportamento dos jogadores e eficácia na grande penalidade. Os resultados demonstraram uma influência da instrução na velocidade dos jogadores e no ângulo de estiramento lateral do guarda-redes, sem alterações da eficácia. De seguida, a cinemática do rematador foi analisada, procurando entender a sua relação com a direcção da bola. As variáveis cinemáticas correlacionadas com a direcção horizontal da bola foram pouco afectadas pela acção simulatória, demonstrando a impossibilidade de encobrir a acção genuína que cumpre determinado objectivo. A altura da bola influenciou a eficácia, apesar dos constrangimentos físicos impostos sobre a variabilidade de movimento dos rematadores na grande penalidade (comparada com outros tipos de remate) terem forçado uma diminuição das correlações entre a direcção vertical da bola e a cinemática dos rematadores. A investigação desenvolvida contribuiu para 1) clarificar a influência de diferentes estratégias no movimento dos rematadores, 2) identificar fontes genuínas de informação para a antecipação da direcção da bola, e 3) determinar a influência da altura da bola na eficácia da grande penalidade.

**Palavras-chave**: grande penalidade, tomada de decisão, percepção-acção, constrangimentos instrucionais, estratégia, informação distribuída, informação local, cinemática, informação preditiva, direcção da bola.

## Publications

A position paper and three experimental papers have been published, submitted to publication or currently being prepared for submission. Those papers represent topics 2, 3, 4 and 5 of this thesis.

## Published / Submitted/ In preparation

**Lopes, J.E.**, & Araújo, D., & Davids, K. (in preparation). Investigative trends in understanding penalty kick performance in association football: An ecological dynamics perspective.

**Lopes, J.E.**, Araújo, D., Duarte, R., Davids, K., Fernandes, O. (2012). Instructional constraints on movement and performance of players in the penalty kick. *International Journal of Performance Analysis in Sport, 12*(2), 331-345.

**Lopes, J. E.**, Jacobs, D. M., Travieso, D., & Araújo, D. (Submitted). Genuine actions lead to genuine information: the case of deceptive and non-deceptive penalty kicks. *Psychology of Sport and Exercise*

**Lopes, J.E.**, Jacobs, D. M., Travieso, D., & Araújo, D. (in preparation). The Importance of Height After Side: Regulation of Penalty Kick Vertical Direction and its Influence on Performance. (??)

## Congress presentations

Some experimental work and subsequent results of this thesis were presented in national and international scientific congresses with refereeing and published in abstract books of those congresses.

**Lopes, J.E.**, Araújo, D., Jacobs, D. M., Travieso, D., & Araújo, D. (2012). Como pode o guarda-redes prever a direcção da bola na grande penalidade?. In *Livro de Resumos* (pp. 26-27). XIII Jornadas da Sociedade Portuguesa de Psicologia do Desporto, 26-27 Outubro, Lisboa, Portugal.

**Lopes, J. E.**, Travieso, D., Jacobs, D., & Araújo, D. (2012). Movement registration and kinematic variables in deceptive and non-deceptive penalty kicks. In *Book of Abstracts* (pp.71), 12th European Workshop on Ecological Psychology, 27-30 June, Madrid, Spain.

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**Lopes, J.E.**, Araújo, D., Fernandes, O., & Davids, K. (2010). Interpersonal dynamics shape decision making in goalkeepers and penalty kickers in performance. In *Book of Abstracts* (pp. 119). European Workshop of Ecological Psychology, 9-12 June, Fréjus, France.

**Lopes, J.E.**, Araújo, D., Fernandes, O., Davids, K., Barreiros, J., & Peres, R. (2010). The entangled decisions of penalty takers and goalkeepers in

association football. In D. Araújo, N. Balagué, R.J. Bootsma, J. Mateus, & V. Correia (Eds.), 2nd International Congress of Complex Systems in Sport and 10th European Workshop on Ecological Psychology, Funchal, Madeira, Portugal. *International Journal of Sport Psychology* (Special Issue), pp. 89-90.

**Lopes, J.E.**, Araújo, D., & Jacobs, D. M. (2010). The complex dynamics of decision making in the penalty kick task in football. In *Book of Abstracts* (pp. 150-151). The 3rd International Congress of Complex Systems in Medicine and Sport, 15-18 September, Kaunas, Lithuania.

## Other publications

During this thesis conception, a paper was published in a national peer-reviewed journal and a parallel paper was published in co-authorship:

**Lopes, J. E**., & Araújo, D. (2012). Relação entre variáveis cinemáticas do rematador e direcção do remate em condição simulatória e não-simulatória na grande penalidade no futebol. *Gymnasium, 1-4*(5), 179-190.

Duarte, R., Araújo, D., Fernandes, O., Fonseca, C., Correia, V., Gazimba, V., Travassos, B., Esteves, P., Vilar, L., & **Lopes, J. E.** (2010). Capturing complex human behaviours in representative sports contexts with a single camera. *Medicina (Kaunas), 46*(6), 408-414.

## Visiting Research

Throughout this body of work several research visits were made to the Department of Basic Psychology of the Autonomous University of Madrid, under supervision of Professor David Jacobs, namely on December 2010, November 2011 and April 2012.

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# Figures

Figures numbering followed chapter numbering.

## Tables

Tables numbering followed chapter numbering.

# 1 General Introduction

Penalty kick in association football is a crucial event that often influences the final score of the game. Additionally, it is a one versus one privileged situation, since it has relatively stable and controllable start and end moments, which are defined by game laws. These two characteristics of penalty kick make it appealing for representative social interactions (Marsh, Richardson, Baron, & Schmidt, 2006) in sports and to develop applications to performance enhancement.

A Gibsonian view of decision-making puts the control of performers' choices on the agent-environment system. Specifically, the individual-environment relationship under task constraints promotes shifts in perceptual-motor behaviours, which are the foundations of decision-making. Such control is possible due to the perception of information to act, which will create new information to be perceived. Moreover, there are specific task demands that constrain that information and the expressed behaviour (Araújo, Davids, Chow, & Passos, 2009). The penalty kick is an event where these demands are particularly evident, with players being pressured to achieve high levels of precision, due to their mutually exclusive goals. Being a one versus one situation, it is reasonable to assume that the information supporting a player's action in the penalty kick is mainly based on opponent's movements. Hence at least at some moment prior to foot-ball contact, movement features should predict players' goal-directed behaviours. Therefore, it is reasonable to assume that the relevant information for accomplish players' goals came from the kinematics of the players. The goal of this thesis is to describe the influence of informational constraints on the penalty kick (Araújo, Davids, & Passos, 2007). By means of a multifaceted performance assessment (i.e. perceptual-motor measurement approaches), this work aims to give a better understanding of the penalty kick performance context. This multi-disciplinary emphasis is focused on the adaptive behaviours of both players, which emerge from the dynamics of their interpersonal interactions during performance under several types of constraints (Araújo, Davids, & Hristovski, 2006).

## 1.1 Explaining the penalty kick: an information-based approach

From an ecological dynamics perspective, decision-making behaviour in the penalty kick emerges from the dynamical interactions of performer-performer (environment) towards specific goals (i.e. to score or to save a goal), influenced by task constraints over time (e.g., players' strategies, task inherent stress, prior experiences) (Lopes, Araújo, Peres, Davids, & Barreiros, 2008).

When a player continuously interacts with a structured environment (e.g., teammates, opponents, spectators, light or wind conditions, surface type), functional patterns of behaviour emerge. The theory of direct perception promoted by Gibson (1979), consider the individual-environment relationship as being grounded on contextual information that affords what is possible to do at a certain moment. In this view, relevant information is the cornerstone of penalty kick's interpersonal dynamics, because it expresses players' intentions. For example, if a penalty taker aims to direct the ball to a certain place, her/his kinematics must reflect the genuine action (i.e., the one that fits their intention) about the direction of the ball (Runeson & Frykholm, 1983). Nevertheless, although the information that allows goalkeepers to anticipate the direction of the ball should be present on penalty takers' movement, it is common to observe deceived goalkeepers (i.e., goalkeepers that dive to the opposite side of ball direction). The success of penalty taker's deceptive action is more related with incapacity of goalkeepers to detect and use relevant information than with an effective ability of the first to dissimulate that information. The perception of information from performance environment does not automatically entail a use of that information for action guidance (Huys, Cañal-Bruland, Hagemann, Beek, Smeeton, & Williams, 2009).

In penalty kick dyadic relation, the decisions of the players must be based on opponent's movements. Since movement can be measured by means of physical variables (e.g., angles of displacement, relative speeds or interpersonal distances), then, physical variables from the penalty taker-goalkeeper-environment system express the behaviour of both players involved (Araújo et al., 2006). This co-dependence established between penalty taker and goalkeeper is well documented on literature. Van der Kamp (2006) demonstrated how this interaction between players influences the outcome of the penalty kick. A keeper-dependent (i.e., when penalty takers act taking into account goalkeeper's actions) strategy seems to decrease the efficacy of penalty takers. From this, one could assume that penalty takers only need to act without considering the action of the goalkeepers if they want to succeed. However, as Van der Kamp and Masters (2008) demonstrated, goalkeepers can shift an initial keeper-independent strategy of penalty takers to a keeper-dependent one. Lopes, Araújo, Duarte, Davids, and Fernandes (2012) demonstrated that this interaction between players evidences coordination patterns that express their coupled relation. By means of specific instructional constraints to penalty takers and goalkeepers, investigators showed not only how players' actions are interdependent but also how efficacy levels could remain constant despite this dependence. As so, in order to study the influence of constraints on performance, experimental tasks should promote the interaction between players in a way that is representative of the environments towards which investigators aim to generalise findings (Dicks, Button, & Davids, 2010).

## 1.2 Aims and structure of this thesis

This work aims to contribute to a better understanding of the factors that influence decision-making process in the association football penalty kick. An ecological dynamics approach of the event is presented as a theoretical framework for the different approaches on the study of the penalty kick performance. Inserted in the ecological dynamics perspective of the penalty kick, the following three chapters are three distinct experimental studies focused on (i) the specific influence of instructional constraints on penalty takers and goalkeepers' behaviours, and also on penalty kick outcome, (ii) the identification of relevant sources of information from penalty takers' movement that predict ball horizontal direction, and (iii) the identification of kinematic variables associated with ball vertical direction and performance, in a highly constrained event as the penalty kick.

The first part of this work (i.e., chapter 2) clarifies the growing influence of penalty kicks in the final score of important clubs and national teams competitions. The growing body of research dedicated to penalty kick supports this statement too. Since this research was implemented under several different perspectives, ecological dynamics is presented as a theoretical framework that integrates all developed work. It is sustained that research should not only consider which information is relevant for the penalty kick performance, but also how constraints can modify (i.e., by changing or masking) that relevant information.

On a first experimental study (chapter 3), penalty takers and goalkeepers' actions were manipulated through specific instructions, in order to examine the hypotheses that: (i) different instructions constrain penalty taker-goalkeeper interactions, influencing performance and outcome of the penalty kick, and (ii) different movement patterns and transitions among these patterns emerge, in order to achieve successful outcomes.

The main goal of the study presented on chapter 4 was to investigate the influence of a deceptive intention on the kinematics of the penalty taker, when a determined ball horizontal (i.e., left or right) direction is required. This investigation aimed to identify local and distributed sources of information on penalty takers' body that predict the horizontal direction of the penalty kick. These information sources allowed testing the principle of non-substitutability of genuine actions in the penalty kick (i.e., the impossibility of penalty taker to deceive in order to achieve a pre-determined ball direction; Richardson & Johnston, 2005).

Finally, in a third experimental study (chapter 5), the research aimed to identify possible predictors of the vertical direction of the ball in the penalty kick.

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Van der Kamp, J., & Masters, R. S. W. (2008). The human Müller-Lyer illusion in goalkeeping. *Perception, 37*, 951-954.

# 2 Investigative Trends in Understanding Penalty Kick Performance in Association Football: An Ecological Dynamics Perspective

## 2.1 Abstract

There is an increasing importance of the penalty kick on the results of club and national football competitions, with a substantial growth in empirical research dedicated to its analysis. There have been different approaches to the study of the penalty kick performance and here we attempt to synthesize the key findings with an Ecological Dynamics theoretical framework. According to this viewpoint, information is the cornerstone for understanding action regulation and its dynamics in penalty kick performance. Therefore, investigators should consider, not only which information sources are most relevant in the penalty kick in representative experimental settings, but also how constraints can channel (i.e., change, emphasize or mask) the relevant information and how these constraints are expressed in players' behavioural dynamics. Due to the broad range of constraints influencing the players' performance in the penalty kick, it is suggested that future research adopts an interdisciplinary performance assessment to overcome the current lack of representativeness in many experimental settings. Such an approach would serve to capture the information-based control of action of both players in this competitive dyadic system.

## 2.2 Introduction

Recently, a growing body of research has been dedicated to studying performance of both individuals involved in the association football penalty kick. Researchers have approached the event from a variety of perspectives, including for example, the application of mathematical models like the Mixed-Strategy Nash Equilibrium to predict penalty kick outcomes (e.g., Azar & Bar-Eli, 2011; Baumann, Friehe, & Wedow, 2011). The influence of several types of constraints, like player strategies (Castillo, Oña, Raya, Bilbao, & Serra, 2010; Lopes, Araújo, Duarte, Davids, & Fernandes, 2012), emotional pressure (Furley, Dicks, Stendtke, & Memmert, 2012; Horikawa & Yagi, 2012), or the effect of an environment scaled to the body dimensions of the players (Furley, Dicks, & Memmert, 2012), constitutes another field of research in the penalty kick, the main findings of which will be presented and discussed later. Lastly, the influence of information for anticipation on players' performance (e.g., Diaz, Fajen, & Philips, 2012; Dicks, Button, & Davids, 2010a, 2010b; Lees & Owens, 2011) has been one of the most recent fields of research in the penalty kick.

At one level of analysis, penalty kicks constitute a one versus one task and can be considered as a dynamical dyadic system (Araújo, Davids, & Hristovski, 2006), in which the performers' relationship is characterised by stable and unstable patterns that emerge from their ongoing interactions (Lopes et al., 2012). Such performance dynamics are based on specifying information (i.e., information from one player's movements that has a direct meaning for the opposing player). For example, a determined angle of a penalty taker's non-dominant foot means that the ball will be directed to a specific goal area (Lees & Owens, 2011). To capture this informational relation between players, experimental settings should ensure that their behaviours correspond to those used in the performance context. Here we argue that experimental settings must provide the same informational variables presented by performance settings (see Araújo, Davids, & Passos, 2007). Hence, research needs to determine which informational variables are most relevant for penalty kick performance (i.e., which ones specify the performers' actions). To achieve such a purpose, performance constraints must be manipulated, since they regulate the available information during action. Manipulations consist of changing information sources, like reducing the run up of the penalty taker or using a foam ball with unpredictable trajectories. Others examples could be to emphasize perception of certain body areas like penalty taker's non-dominant foot, or even inciting the penalty taker to visualize a goalkeeper's movements instead of the ball. Finally, since deception is an integral aspect of penalty kick performance, the strategy of masking actions should be considered in penalty kick experimental and training tasks. To instruct goalkeepers to move first to the opposite direction of diving, or suggest that penalty takers could lean towards both sides while kicking, are some examples of performance manipulations that could be considered.

An ecological dynamics (Araújo et al., 2006) perspective on the penalty kick (Lopes, Araújo, Peres, Davids, & Barreiros, 2008) constitutes an important theoretical background for integrating recent findings on the event. This paradigm can help fit major topics of penalty kick investigations like: 1) action emergence from the interaction of several constraints, like strategies employed by players, or emotional demands, and 2), the search (by means of players' interaction) for relevant informational sources to guide actions. The remainder of this paper is divided into three main sections to examine how penalty kick performance has been investigated in the sports sciences. To characterise this body of work, an Internet search on PubMed and Scholar Google databases was instigated between July and November 2012. The following search reference terms were used: ‘soccer penalty kick’, ‘football penalty kick’, and ‘penalty kick performance’. In the first section, the growing influence of penalty kicks shootout in the results of important male clubs and national teams’ championships and tournaments is presented as a plausible reason for the prevalence of investigations dedicated to this event over the past few years. Typically in these analyses, there have been very few attempts to provide an overarching theoretical framework to characterise penalty kick performance. In the second section, we suggest how an ecological dynamics framework provides a potential characterisation of the event to sustain a better organization of the extant literature. Finally, directions for future research are indicated in order that sports scientists can develop a better understanding to improve performance in the penalty kick.

## 2.3 The Critical Role of Penalty Kicks in the Knockout Phase of Major Football Competitions

In this paper our main focus is on performance in male elite competitive football, of which the penalty kick as a relatively stable sub-phase. Performance of players is constrained by specific rules including: (i) the goalkeeper is confined to the goal line until the moment the penalty taker kicks the ball, (ii) the penalty taker cannot stop completely after run up initiation, and (iii) event is clearly initiated (i.e., referee's whistle) concluded (i.e., penalty kick outcome). These features are related to the increasing influence of the penalty kick on the final outcome of matches and it is clearly a valuable task to conduct representative experiments of performance behaviours. Hence, experimental set up in the penalty kick has to be conceived in a way that it represents the behavioural (performance) context to which results are intended to apply (Lopes et al., 2008). The growing importance of the penalty kick on match outcomes can be empirically verified by the increasing number of high-level games by clubs and national teams that have been decided through a penalty kick shootout. Figure 1a) presents two different, although complementary, tendencies in UEFA CHAMPIONS LEAGUE® and FIFA WORLD CUP™.

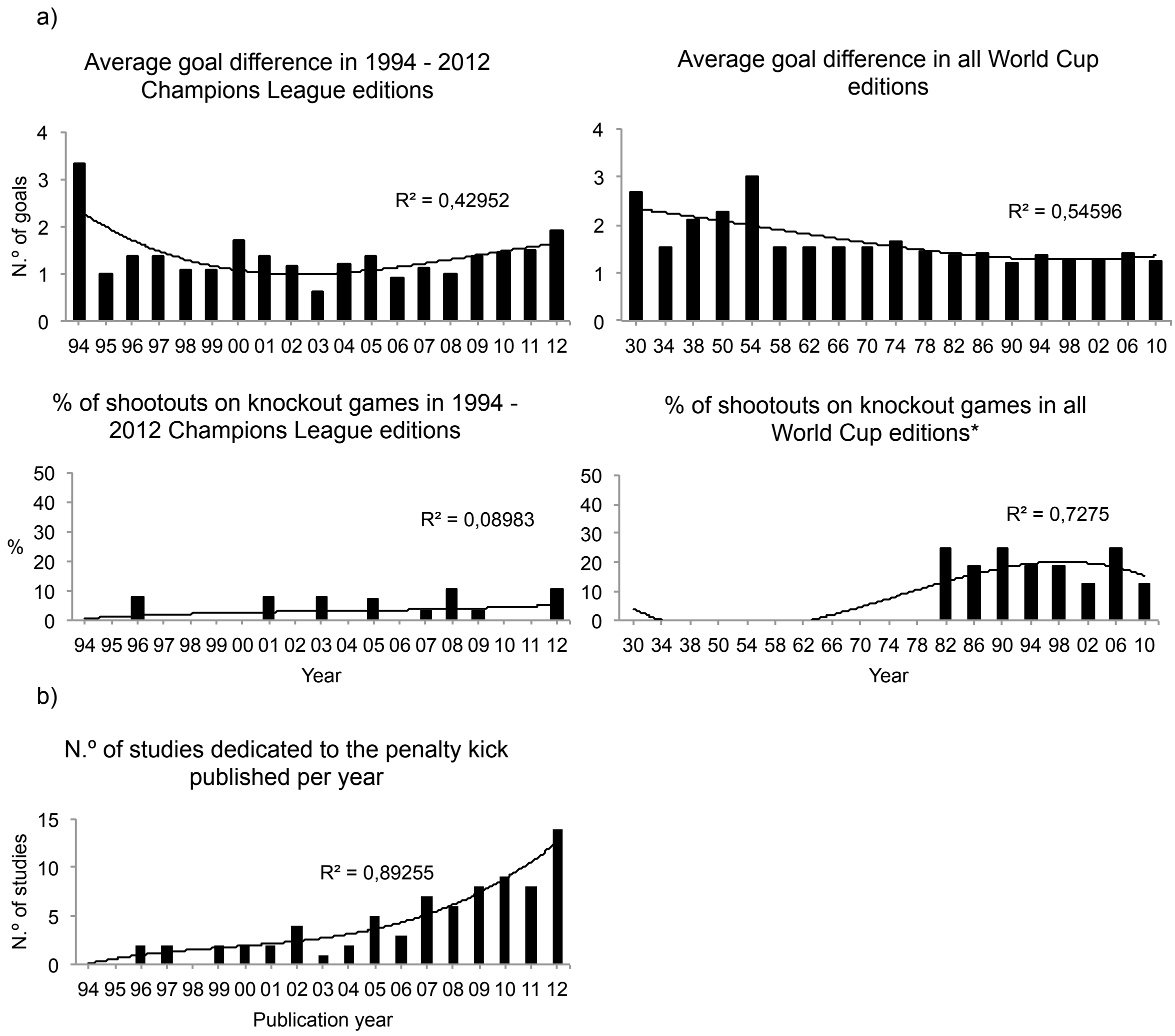


Figure 2-1. (a) Average goal difference (AGD) and percentages of shootouts played in knockout games on 1994-2012 UEFA CHAMPIONS LEAGUE® and in all FIFA WORLD CUP™ editions. (b) Number of studies exclusively dedicated to the penalty kick, published from 1994 until November 2012. Data available from www.uefa.com.

* 1950 WORLD CUP™ edition had no knockout phase. All phases were decided in a championship (i.e., points aggregated) format.

The two upper graphs of Figure 1a) show a reduction of differences in goals scored by each team in national competitions, although in club competitions the average goal difference presents a relatively constant value between one and two goals. This observation signifies that there is a trend for the scores of games to become balanced in the knockout phase of the competition. In the club tournaments the difference between the teams' scores remained constant until the end of the match. The data suggest an increasing possibility for a match to be decided through penalty kick shootouts in the knockout phases of national teams' competitions. This tendency is observed in the bottom-right graph of Figure 1a) by an increasing percentage of shootouts in WORLD CUP™ knockout games since 1982. Given these competitive format tendencies, it is not surprising to observe an unambiguous increase in the scientific publications on the penalty kick sub-phase of the game, which is illustrated by the plot of Figure 1b). Next, we focus on the content of such research and apply an ecological dynamics perspective to integrate the different findings and research paradigms.

## 2.4 An Ecological Dynamics Approach to the Penalty Kick

From an ecological dynamics perspective, decision-making behaviours in the penalty kick sub-phase of association football emerge from the interactions of performers when trying to achieve opposing individual aims (e.g., to score a goal or to save a goal). Penalty takers intend to score a goal by placing the ball into a location where they perceive the GK cannot reach before it crosses the goal line. Goalkeepers, in turn, try to increase their range of action through different strategies, while trying to anticipate where penalty takers will place the ball.

The perceptual guidance of the actions of penalty takers and goalkeepers is the basis for a *prospective* control of action (Montagne, 2005) where performers control their actions based on the difference between what they are currently doing and what they need to do in order to accomplish their individual goals (Lopes et al., 2008). This information-based control strategy is the theoretical basis for assuming a correspondence between players' behaviours in both performance and experimental contexts. A key aspect is identification of the informational variables that are used to guide players' behaviours in the penalty kick context. In the penalty kick task, perceptual judgments made by players must be based on a direct opponent's movements, in this unique dyadic situation. Since movement can be measured by means of physical variables (e.g., angles of displacement, relative speeds or interpersonal distances, i.e., the behavioural dynamics, Warren, 2006), then, physical variables from the penalty taker-goalkeeper-environment system express the behaviour of both players involved (Araújo et al., 2006).

Next, we analyse the relationship between recent investigations and the key theoretical issues of an ecological dynamics perspective of the penalty kick, such as: 1) the dependence of action on different (informational) constraints, 2) the performers' search for relevant information to achieve their goals, and 3), the ability of competitors to induce informative and misleading interactions between each other.

### *2.4.1 Informational constraints and biophysical variables define directed behaviour in penalty kick performance*

The interaction of penalty taker and goalkeeper is expressed by biophysical variables (e.g., angles, speeds or distances of the actions of the two performers) measured during performance (Correia, Araújo, Vilar, & Davids, 2012). For example, Lopes et al. (2012) showed how the run up of the penalty taker is coordinated with the diving angle of the goalkeeper, depending on the different strategies (i.e., task constraints) performed by each player. The relationship between the different types of constraints studied in the penalty kick and the variables that were used to measure their influence on the penalty kick performance are presented in Table 1. The first four studies used video footage of penalty kicks performed in competition. Some (Azar & Bar-Eli, 2011; Baumann et al., 2011) applied mathematical models to predict the outcomes. Bar-Eli and Azar (2009) and Zhou and Inomata (2009), instead, proposed specific individual constraints (e.g., level of satisfaction of players or kick technique) that might have repercussions on the outcomes. Despite the merits of these approaches (e.g., the notion that mathematical models like the Mixed-Strategy Nash Equilibrium can reliably explain penalty kick outcomes), the relationship between spatiotemporal constraints and biophysical variables (Correia et al., 2012) has never been considered for analysis. Hence, the use of sequences of categorical data (e.g., optimal penalty taker strategy: 15º-45º angle of approach followed by an inside kick to the top left corner of the goal; see Zhou & Inomata, 2009) does not explain how, for example, is it possible that different strategies performed by players correspond to similar outcomes (Lopes et al., 2012). In favour of this argument, and contradicting data of Zhou and Inomata (2009), Scurr and Hall (2009) reported no significant differences in kicking accuracy between different approach angles. In more detail, although players' performance in the penalty kick depends on ever-changing task and environmental constraints, performers can maintain their efficacy, through their adaptive skill (Lopes et al., 2012; cf. Davids, Araújo, Button, & Renshaw, 2007). This ability in skilled performers can only be captured through using time-continuous measures, rather than recording discrete performance variables.

With respect to different strategies used by penalty takers, there are two main action modes: they decide where to place the ball before movement initiation (goalkeeper-independent strategy), or that decision emerges from the interaction emerging between penalty taker and goalkeeper during penalty kick performance (goalkeeper-dependent strategy). Castillo et al. (2010) suggested that goalkeepers are more able to identify advance cues when facing penalty takers performing in a keeper-independent strategy. On the other hand, Van der Kamp (2006) and Bowtell, King and Pain (2009) related a keeper-independent strategy to higher success rates by penalty takers. This was suggested since penalty takers need at least 350 ms before contact to re-direct the penalty kick if they adopt a goalkeeper-dependent strategy. The application of biophysical measures may enlighten how penalty takers change from a keeper-independent to a keeper-dependent strategy. For example, high values of approach speed and reduced angular displacement (i.e., running in an almost straight line to the ball) correspond to an action pattern closer to a keeper-independent strategy. This implies that penalty takers can reduce action timings and increase ball speed, when they decide where to place the ball prior to ball contact.

Due to the penalty kick's role in the final score, individuals cope differently with the emotions related to the penalty kick's pressure (Moll, Jordet, & Pepping, 2010). Hence, some recent investigations have addressed the particularities of these individual constraints as the event unfolds. Studies have shown an association between time spent by the penalty taker to initiate movement and penalty kick outcome. Shorter response times by the penalty takers were linked to worse performance than longer times (Jordet, Hartman, & Sigmundstad, 2009). The manipulation of the level of pressure through: 1) limited time for action (Navarro, Miyamoto, Van der Kamp, Morya, Ranvaud, & Savelsbergh, 2011), 2) comparison with other penalty takers' performance (Horikawa & Yagi, 2012), or 3), players' individual focus on promotion (i.e., focus on accomplishments and aspirations like scoring the penalty kick) or prevention (i.e., a focus on safety and responsibilities, like not missing the penalty kick; Plessner, Unkelbach, Memmert, Baltes, & Kolb, 2009), tend to be associated with penalty kick outcomes. This influence suggests that, during performance, emotions somehow constrain players' actions, affecting goal-directed behaviours. These previous investigations did not consider the specificities of the relation between spatiotemporal constraints and biophysical variables. To understand and evaluate this relation, time-continuous measures and the manipulation of task constraints need to be considered, in the ongoing regulation of performance.

Table 2-1. Constraints identified and the variables used to measure their influence on performance and outcome

| Study | Identified Constraints on Performance | | | Variables |
|---|---|---|---|---|
| | Environmental | Task | Individual | |
| Azar & Bar-Eli (2011) | | | Players' utility based on their PK performance | Dive direction<br>PK direction<br>PK outcome |
| Baumann et al. (2011) | | | Penalty takers' ability to play | Dive lateral<br>PK direction<br>Kicking foot<br>PK outcome |
| Bar-Eli & Azar (2009) | | Upper goal areas are more successful and harder to hit | Goalkeepers' preferences | Dive direction<br>PK direction<br>PK outcome |
| Zhou & Inomata (2009) | | | | Run-up angle<br>Target ball direction<br>Kicking technique<br>PK outcome |
| Jordet et al. (2009) | Games' status lead to quicker kicking and more misses | Shorter available timings to act lead to poorer performances | | PK time phases<br>PK outcome |
| Navarro et al. (2011) | Surroundings noise level influence players' pressure level | | Pressure to answer (i.e., shorter time) reduced efficacy | Pressure condition<br>Correct responses<br>Available time for performance<br>Physiological data |
| Horikawa & Yagi (2012) | | Different expected success rates affect performance | Pressure to succeed increases anxiety and lowers efficacy | Pressure condition<br>Anxiety level<br>PK outcome |
| Plessner et al. (2009) | | | Motivational level *per se* does not predict performance | Regulatory focus<br>PK outcome |
| Dicks et al. (2010) | | | Individual's body dimensions affects his/her action timings | Movement timings<br>Ball flight timing<br>PK outcome |
| Castillo et al. (2010) | The actions of the players influence the ones of their opponents | Limited time to change ball direction | | Dive direction<br>PK direction<br>PK outcome<br>Individual strategy |
| Wood & Wilson (2010) | Context structure influences gaze pattern | Restrictions to gaze affect ball direction | | PK direction<br>Fixation duration |

Regarding individual and task constraints' manipulations, Dicks, Davids and Button (2010) investigated the action timings of goalkeepers with different action capabilities (e.g., different displacement speeds, limb lengths or body statures) when facing deceptive and non-deceptive penalty kicks. Distinct action capabilities influenced the timing for action initiation and a inverse relation between action capability and response initiation was reported (i.e., the faster the goalkeeper, the longer he waited before diving). Gaze behaviour has also been investigated with Wood and Wilson (2010) finding that gaze and ball directions are highly related (i.e., the areas fixated by penalty takers are closer to where they direct the ball) when gaze was self-regulated. Relatedly, when negative instructions have been imposed on gaze (e.g., ‘do not look at goalkeeper when approaching the ball’), penalty takers demonstrated a tendency to do the opposite (i.e., to look at goalkeepers; see Bakker, Oudejans, Binsch, & Van der Kamp, 2007). These findings reflect how different types of constraints interact during penalty kick performance. By means of a specific instruction, an initial strategy (e.g., keeper-independent) can be converted into a different one (i.e., a keeper-dependent). These attempts to improve the study of goal-directed behaviour in the penalty kick as a result of the interactions between players and the action context deserve to be acknowledged. However, there is still a lack of work investigating which information is actually relevant in penalty kick performance. If the information that supports a player’s action is mainly based on his/her opponent’s movements, then, at least at some moment prior to foot-ball contact, movement features should predict goal-directed behaviour. Therefore, it is reasonable to assume that the relevant information for goal-directed behaviour is sourced in the kinematics of the players. It is important to clarify how players search and use relevant information from an opponent’s kinematics, in order to achieve performance goals.

### *2.4.2 The Role of Relevant Information on penalty kick goal-directed behaviours*

Information becomes relevant if it guides the action of the players towards their goals. Moreover, to be relevant for action, contextual information must be scaled to each individual’s capabilities (i.e., effectivities, Turvey &

Shaw, 1999). Hence, information in the penalty kick allows decision-making behaviour because it specifies actions that penalty takers and goalkeepers are able to perform to achieve their goals.

In terms of information sources, areas like torso, lower kicking leg, non-dominant leg (Dicks et al., 2010a), head (Button, Dicks, Haines, Barker, & Davids, 2011) and ball (Piras & Vickers, 2011) have been reported as places toward which goalkeepers direct their gaze. Although local information sources were identified by means of goalkeepers' gaze analysis, the sources that actually predict the outcome (i.e., ball direction) are yet to be identified. This distinction between sources towards which performers direct their gaze and sources that predict future events is non-trivial. As already demonstrated, perception of information from performance environment does not automatically entail a use of that information for action guidance (Huys, Cañal-Bruland, Hagemann, Beek, Smeeton, & Williams, 2009).

The *in-situ* research paradigm applied by Dicks and colleagues (2010b) showed how goalkeepers are susceptible to penalty takers' deceptive movements when available information is constrained. Nevertheless, it would constitute an upgrade to their research if an experimental design would be conceived to analyse, for example, to what extent are goalkeepers' movements synchronized with the emergence and dissolution of kinematic information from penalty takers. In order to examine this coupled relation, one first has to identify the sources of information directly related with performance. For example, in terms of goalkeepers' movement anticipation, it is important to identify what information predicts the direction of the ball. Diaz and colleagues (2012) and Lees and Owens (2011) identified both local and distributed sources of information highly correlated with ball direction. Non-dominant leg seems to be a consensual source of information (i.e., a source simultaneously identified by goalkeepers' gaze analysis and highly correlated with ball direction). Despite the merits of these findings, the importance of representative designs emphasized in some penalty kick studies (Dicks et al., 2010a; Lopes et al., 2008; cf. Araújo, et al., 2006) has been to some extent neglected in their experiments, since: 1) penalty takers were asked to shoot the ball into a non-standard goal (Lees & Owens, 2011) or into a small canvas substituting a goal (Diaz et al., 2012); 2) Penalty kicks were shot from a distance shorter than the regular 11 m; and 3), no goalkeepers were present when penalty kicks were taken.

### *2.4.3 The role of interaction between players on penalty kick decision-making*

The relevance of information was evidenced in the research of Núñez, and colleagues (2009, 2010), who found that, explicitly revealing specifying information about goalkeepers' actions to penalty takers allowed the latter to improve their performance. However, despite demonstrating the relevance of specifying information, this procedure biased the interactions between players, since the information pick up process was directed and not exploratory. Moreover, different types of constraints interact during penalty kick performance, and the context is constantly changing, with relevant information perishing and emerging. Araújo and colleagues (2006) summarized this ever-changing contextual information as a set of possible choices dynamically formed and dissolved by changes in key contextual variables. From this perspective it is necessary to explain how the relevant variables in the penalty kick are used during the interactions between penalty taker and goalkeeper (Araújo & Davids, 2009). Analysis of stable and unstable patterns of coordination (Lopes et al., 2012) revealed exploratory behaviours of players, when pursuing relevant information sources. Perceiving these action possibilities is a key feature of skilled performance in the penalty kick (Araújo & Davids, 2009; Fajen, Riley, & Turvey, 2009), particularly when one can assume the presence of deceptive action (i.e., any non-relevant action that intends to mask relevant information; see Dick et al., 2010b) in the event.

Some research has attempted to observe how deceptive action influences players' movements and performance outcome (Dicks et al., 2010b). A great number of response corrections by goalkeepers on deceptive penalty kicks corresponded to significantly lower performance on those trials, compared with non-deceptive ones. These findings led Dicks and colleagues to conclude that anticipation based in information sources from early moments of the penalty kick could be either beneficial (for non-deceptive) or detrimental (for deceptive) for goalkeepers. This is in line with the conclusions of Smeeton and Williams (2012), who stated that anticipation accuracy for non-deceptive penalty kicks was significantly greater than for deceptive ones on their initial (i.e., more distant to ball contact) temporal occlusion windows.

Even in deceptive penalty kick, there should be some penalty takers' movements that specify the direction that they intend to give to the ball. Runeson and Frykholm (1983) synthesized this assumption, by saying that the kinematic properties of an individual's movements express not only his/her identity, but also his/her actions and intentions. The next step in penalty kick research is likely to aim to observe how players' perceptually different profiles (i.e., different information sources that they use to ground their actions) support to fulfil their opposite intentions. When related to performance and outcome, the differences in information use in the penalty kick will allow investigators to profile which information source(s) is/are relevant at each moment.

## 2.5 Future research in the penalty kick: perceiving intentions on players' actions in representative experimental tasks

From an ecological dynamics perspective of the penalty kick, the information that guides action must specify the relevant properties from the environment (e.g., the other player) (Araújo et al., 2006). Recommendations from penalty kick studies outcrop this statement under different – yet related – forms: '*the necessity of broader and better data sets, that cover the complete environment*' (Berger, 2009), or '*the employment of standardized association football contexts, to examine the reliability of models' predictions*' (Azar & Bar-Eli, 2011). This demand for more representative designs of performance contexts is expressed also by Lees and Owens (2011), who underlined the influence that deceptive action – which was not taken into account in their work – could have on the camouflage of kinematic cues. Van der Kamp (2011) expresses similar concerns by stating that future research should solve the absence of direct interactions between goalkeepers and penalty takers on penalty kick investigation.

The relevance of representative design is much promoted on recent research. Even in studies performed *in situ*, he representativeness continues to be enhanced (see Dicks et al., 2010a, 2010b). Dicks and colleagues argued that future experimental conditions should offer opportunities for action that represent the functional behaviours that define an athlete's expertise. In sum, the lack of representativeness of experimental designs to capture, in a time-continuous fashion (Correia et al., 2012), goal-directed behaviour, legitimates the necessity of situations more similar to competitive scenario (Castillo et al., 2010). To do so, experimental set ups need to include ecological constraints that assure the presence of information from players' movement kinematics during actual performance. Although these specifying properties of information have already been found in performance of other tasks, like heading direction (Warren, 2004), goal fixation (Wilkie & Wann, 2003), or intercepting moving targets (Fajen & Warren, 2004), they still remain to be identified in the penalty kick. Due the continuous emergence and dissolution of information during the event, the identification of *what* and *when* action-relevant information becomes available represents a major challenge for future work in the penalty kick.

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# 3 Instructional constraints on movement and performance of players in the penalty kick

## 3.1 Abstract

The influence of different instructional constraints on movement organisation and performance outcomes of the penalty kick was investigated according to participant age. Sixty penalty takers and twelve goalkeepers from two age groups (under 15 and under 17) performed 300 penalty kicks under five different task conditions, including: no explicit instructional constraints provided (Control); instructional constraints on immobility (IMMOBILE) and mobility (MOBILE) of goalkeepers; and, use of keeper-dependent (DEP) and independent (INDEP) strategies by penalty takers. Every trial was video recorded and digitised using motion analysis techniques. Dependent variables (DVs) were: movement speed of penalty takers and the angles between the goalkeeper's position and the goal line (i.e., diving angle), and between the penalty taker and a line crossing the penalty spot and the centre of the goal (i.e., run up angle). Instructions significantly influenced the way that goalkeepers (higher values in MOBILE relative to Control) and penalty takers (higher values in Control than in DEP) used movement speed during performance, as well as the goalkeepers' movements and diving angle (less pronounced dives in the MOBILE condition compared with INDEP). Results showed how different instructions constrained participant movements during

performance, although players' performance efficacy remained constant, reflecting their adaptive variability.

## 3.2 Introduction

Performance behaviours in the football penalty kick are influenced by many interacting constraints (organismic, environmental, task), whose magnitude of influence can change as the event unfolds. These influences on performance constraints induce movement adaptations which yield different movement solutions to fit different circumstances, while obtaining similar performance outcomes (i.e., score or save a penalty). This adaptive variability of human performers is a specific case of neurobiological system degeneracy or adaptive movement variability (Edelman and Gally, 2001). Demonstrations of adaptive movement variability have also been observed during performance in other sports tasks such as basketball dribbling and shooting (Araújo et al., 2004) and boxing (Hristovski et al., 2006). Other studies have reported a relation between performer morphology, instructional constraints and movement performance and/or task outcomes in other 1v1 sub-phases of team sports (e.g., Cordovil et al., 2009). In that work, the physical variables expressing the performers' decision-making behaviours were investigated and revealed that instructional constraints, such as risk-taking and conservative instructions, influenced participants' decisions and actions. Based on these findings on 1v1 sub-phases of team games, further research on the decision-making behaviours of both opponents interacting in the football penalty kick is needed. In our study, it was expected that the specific behaviours of participants would emerge from their on-going dynamical interactions, with respect to their particular task goals, and taking into account their individual strategies for the event.

Previous investigations of the penalty kick can be divided into those related to performance efficacy measures and those reporting process-tracing measures. Investigations of performance efficacy have typically used a standard notational analysis approach. Data are collected from video observation of competitions showing the percentages of penalty kicks scored/saved or relations between performance efficacy and, for example, player's field position, fatigue or penalty kick relevance to the final result of a game (Jordet et al., 2007). It has been observed that differences in success between of penalty kickers and goalkeepers is related to their behaviours, including: (i) performance differences emerge between left- and right-footed penalty takers (McMorris and Colenso, 1996); and (ii), goalkeepers who take a step forward (despite this strategy being prohibited by the laws of the game), and remaining upright during the penalty taker's approach run, are more likely to save the kick (Hughes and Wells, 2002).

In research on the penalty kick using process-tracing measures (i.e., analysing the movements that underlie performance processes), a number of conclusions have emerged: (i) the hip and non-kicking leg are relevant sources of information when goalkeepers anticipate the direction of a penalty kick (Savelsbergh et al., 2002, 2005); (ii) verified in video-based and *in situ* studies, goalkeepers spend more time fixating the movements of the penalty taker, than the ball, when movements are limited by experimental task constraints (Dicks et al., 2010a). However, when experimenters required goalkeepers to only provide verbal responses, joystick movements, or simplified body movements (i.e., nonrepresentative interceptive actions) during a penalty kick simulation, fixation time is almost equally distributed between opponent movements and the ball (see Dicks et al., 2010a); and (iii), successful goalkeepers stay still for longer than less successful goalkeepers, before moving to stop the penalty kick (Savelsbergh et al., 2002, 2005). For example, Dicks et al. (2010b) observed that, by waiting longer before initiating actions, goalkeepers still had enough time to act and reduce the possibility of penalty takers disguise their kick direction. Identification of the relationship between specific instructional constraints and the actions and outcomes of performers represents a major issue to investigate (see Bakker, Oudejans, Binsch, & Van der Kamp, 2007; Cordovil, Araújo, Davids, Gouveia, Barreiros, Fernandes, & Serpa, 2009). In the present study, we investigated how decision-making behaviours and performance outcomes of both participants were specifically shaped by different task-related instructional constraints during the penalty kick (for a review see Lopes et al., 2008). This analysis was informed by Van der Kamp's (2006) work on the kickers' dependence or independence of goalkeepers' actions and Kuhn's (1988) identification of goalkeepers' dives at or before ball contact and anticipation of the kick based on perceptual strategies. We also examined Savelsbergh et al.'s (2002, 2005) assumption that successful goalkeepers tend to adopt an immobility strategy and observations by Wood and Wilson (2010) who suggested that participants were more distracted by a moving goalkeeper than a stationary one. An interesting observation from previous work was Jordet et al.'s (2007) finding that players of 18-22 years old scored more often (85.2%) than players of 23-28 years old (77.6%) and 29-35 years old (78.1%). Younger players may be less disposed to stress or have fewer experiences, their own or from observation of others, of failures in the penalty kick. We sought to understand whether the same age-based effects would be observed between development groups of players aged 15 and 17 years.

Despite recent trends to enhance the representative task design (Brunswik, 1956) of experiments in sport (Dicks et al., 2010a,b; Pinder et al., 2011a,b), the majority of data on the penalty kick have been obtained without actually studying the direct interactions between players during performance of the penalty kick. Although some studies suggest that behaviours of both players in the penalty kick are interrelated (e.g., Morya et al., 2003; Van der Kamp, 2006), there have been few attempts to analyse the interactions between performers in the penalty kick (for exceptions see Dicks et al., 2010a,b).

In order to enhance representative design, therefore, empirical studies of the penalty kick situation should: (i) be conducted in a setting where a penalty kick is actually performed, (ii) involve both players in the task to ensure the existence of a dyadic system (i.e., a direct competitive interaction), and (iii), through different instructional constraints, induce the possibility of variable decisions and behaviours emerging from goalkeepers and penalty takers in competitive performance.

Specific instructions to perform these strategies were manipulated to examine our hypotheses that: (i) different instructions would constrain performance and outcome of the penalty taker-goalkeeper interactions, according to the age of participants, and (ii), different movement patterns (i.e., different directions of run up approach to the ball and dive, assessed by spatial-temporal variables of performance), and transitions among these patterns (i.e., sudden changes to a previous stable state on variables value), would emerge under different instructional constraints, in order to achieve successful outcomes.

## 3.3 Methods

### *3.3.1 Participants*

Two groups differing in age provided the penalty takers and goalkeepers who were selected to perform 300 penalty kicks (150 per age group). To observe effects of instructions on how developing players adapted to different types of instructions, both under 15 (U15 years; $M_{age}$= 13.5, *SD* = 0.51 years) and under 17 (U17 years; *M* = 15.6, *SD* = 0.50 years) groups consisted of 30 penalty takers each, plus seven U15, and five U17 goalkeepers. All participants were elite development players, currently playing in the highest Portuguese national youth league. Informed consent was obtained from the players' club and from all participants and their parents, after ethical approval for the study by a local university committee.

### *3.3.2 Variables*

Two independent variables were manipulated in the samples: age of participants (U15 and U17) and instructional constraints provided to guide the performance strategies of penalty takers and goalkeepers. To isolate effects of instructions, a control condition and four treatment conditions were included, where the strategies adopted by penalty takers and goalkeepers were manipulated. Only the performance instructions for one participant in the dyad (either penalty taker or goalkeeper) were manipulated in each trial, so that we could observe effects of instructions on specific individuals. Instructional constraints for all participants were manipulated as follows:

- Control condition: No specific instructional constraints placed on performance strategies for both players: basic task outcome-related verbal instructions were simply “try to score the penalty kick” (penalty taker) and “try to stop the penalty kick” (goalkeeper);

- Independent Condition (INDEP): ‘Keeper-independent’ strategy (penalty taker) and basic instructions (goalkeeper): verbal instruction to penalty taker was “choose one of these areas to place the ball (see Figure 3-1)” and to goalkeeper “try to stop the penalty kick”. An image of a goal (Figure 3-1) was presented to penalty takers for them to choose the area of penalty kick placement. Their choice was recorded and confirmed through video analysis;

- Dependent Condition (DEP): ‘Keeper-dependent strategy (penalty taker) and basic instruction (goalkeeper): verbal instruction to penalty taker was “you must decide the ball’s direction during the run up by looking at the goalkeeper positioning and behaviour” and to the goalkeeper “try to stop the penalty kick”. Comprehension was confirmed after each trial by asking penalty takers whether they had followed the provided instruction;

- Immobility Condition (IMMOBILE): Basic instruction (penalty taker) and immobility instruction (goalkeeper): verbal instruction to penalty taker was “try to score the penalty kick” and to the goalkeeper “stay still as long as possible and try to stop the penalty kick”;

- Mobility Condition (MOBILE): Basic instruction (penalty taker) and mobility (goalkeeper): verbal instruction to penalty taker was “try to score the penalty kick” and to goalkeeper “jump side-to-side and try to stop the penalty kick”.

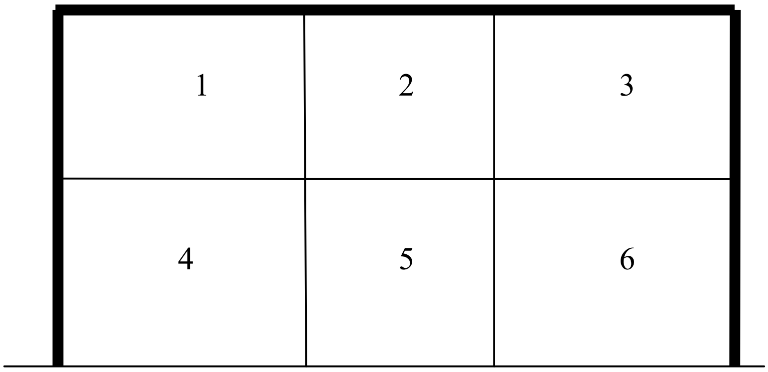


Figure 3-1. A schematic representation of the goal area for the experimental task (frontal view). Numbers from 1 to 6 categorized ball’s direction in INDEP condition.

Adherence to these strategies was checked as follows: 1) for the INDEP condition investigators verified that all the players kicked to the chosen areas, 2) for the DEP condition, no specific check was made due to the specificity of this strategy, 3) for the IMMOBILE condition, we verified that the goalkeeper stayed still during for the whole of the kicker’s run up, and 4), for the MOBILE condition, we verified that goalkeepers moved across the goal line during the kicker’s run up. Trials where these criteria were not met were excluded for further analysis.

Dependent variables included performance outcomes and process-tracing measures, such as the spatial-temporal organisation of each participant’s movements. Performance outcome measures for penalty kickers were categorized as: 1 – “ball missed goal/hit post/bar/save”, 2 – “goal after initial goalkeeper’s interception” and 3 – “goal”. Performance outcome measures for goalkeepers were classified as: 1 – "goal", 2 – "goal after initial goalkeeper's interception" and 3 – "save/ball missed goal/hit post/bar". Process-tracing measures included: (i) mean movement speed ($m.s.^{-1}$) of penalty takers during run ups; (ii), mean movement speed of goalkeepers ($m.s.^{-1}$) during the run up, (iii) variations in the angle (radians) between the goalkeeper's positioning and goal line over time (i.e., diving angle). If goalkeepers stayed on the goal line, the angle assumed a zero value. When goalkeepers made a forward displacement, the angle was measured from the final position to the goal line (Hughes & Wells, 2002), and (iv), angle (radians) of each penalty taker and the ball (McMorris & Colenso, 1996) during the run up approach, measured from penalty taker's actual position to a hypothetical line that crosses the penalty spot and the midpoint (i.e., 3.66m) of the goal.

### *3.3.3 Procedures and apparatus*

The 300 penalty kicks were divided into five sets of 60 penalty kicks (i.e., 30 per condition for each age group). Performance in all conditions was counterbalanced across all participants. The first set of penalty kicks (i.e., penalty taker-goalkeeper both basic instructions) was defined as the control condition, with the remaining four sets forming the experimental treatments. Each penalty taker (in both age groups) took one penalty kick per set (i.e., 30 penalty kicks divided by 30 penalty takers in each set). Each U17 goalkeeper faced six penalty kicks (i.e., 30 penalty kicks divided by five goalkeepers) and each U15 goalkeeper faced four or six penalty kicks per set, i.e., 30 penalty kicks divided by seven goalkeepers resulted in four penalty kicks faced by six goalkeepers, while the seventh goalkeeper performed against six penalty kicks.

Participants were rotated to avoid the formation of the same player dyads from one set to the next.

A digital video camera (25Hz) was placed in front of each goal; 6m behind the penalty kick mark and behind the kicker, recording the performance of both participants in the penalty kicks. All penalty kicks were performed according to the laws of association football.

### *3.3.4 Data treatment*

After collecting on-field data, image files were digitised with TACTO software (Fernandes et al., 2010). This process yielded the virtual coordinates (i.e., in pixels units) of players' movement displacement trajectories on field. Then, the bi-dimensional direct linear transformation method (2D-DLT) (Abdel-Aziz and Karara, 1971) was used to convert virtual into real pitch coordinates (i.e., in meters), with five control points, using dedicated routines implemented in MATLAB® 9.0 (The Mathworks, Inc., Natick, MA, USA) (for further details of this motion analysis technique see Duarte et al., 2010). Descriptive analyses of players' process-tracing measures were performed for each Age group and Condition. Also, a Friedman's test was applied to verify whether different performance conditions affected participants' performance outcomes (Table 3-1). A descriptive analysis of the dynamics of the players in each dyad, using the goalkeeper-goal line angle and the penalty taker-ball angle was performed (Figure 3-2). Correlations between the penalty takers' performance outcomes and the process-tracing measures (i.e., penalty takers' speed and angle of run up to the ball) were undertaken (Table 3-2). The same statistical analysis was implemented between goalkeepers' performance outcomes and their process-tracing measures (i.e., goalkeepers' speed and goalkeepers' angle to goal line). Next, a 5 (Conditions)*2 (Age Group) mixed-model ANOVA was performed to identify possible main effects of Age Group (between-participants factor) and Condition (within-participants factor), and interaction effects of Age Group*Condition for process-tracing measures. A Greenhouse-Geisser correction factor was used in order to adjust the degrees of freedom of the error variance term when the sphericity assumption was violated in the RM variable (Schultz and Gessaroli, 1987). Alpha levels were set at $p<.05$. All statistical analyses were performed using IBM® SPSS® 19.0 software.

## 3.4 Results

Descriptive statistics for performance outcomes and process tracing measures are presented in Table 3-1. For both age groups, the Friedman's test showed no differences between conditions in the penalty takers' performance outcomes ($\chi^2$ = 5.173, $p$ = .270) and the goalkeepers' outcomes ($\chi^2$ = 4.528, $p$ = .339). For the variable penalty takers' speed, results revealed the highest mean values in the CONTROL condition. U15 Age group displayed lower values in goalkeepers' speed in the CONTROL condition in comparison with experimental conditions. The run up approach angle of penalty takers was also lower in the CONTROL condition for the U17 Age group. An inter-group comparison showed that, with the exception of the CONTROL condition, U15 goalkeepers always displayed higher mean values for the goalkeeper-goal line angle.

Table 3-1. Descriptive statistics of outcome and process tracing measures per Age group and Condition

| Group | Condition | PT speed (m.s.$^{-1}$) (M±SD) | GK speed (m.s.$^{-1}$) (M±SD) | Angle GK-goal line (rad) (M±SD) | Angle PT-ball (rad) (M±SD) |
|---|---|---|---|---|---|
| U15 | CONTROL | 3.65±2.19 | 1.71±.67 | 1.29±.31 | 2.16±.66 |
| | INDEP | 2.41±1.60 | 1.81±1.42 | 1.46±.29 | 2.12±.68 |
| | DEP | 2.21±1.42 | 1.74±.88 | 1.51±.20 | 2.17±.70 |
| | IMMO | 3.46±1.88 | 1.88±.98 | 1.34±.26 | 2.01±.87 |
| | MOB | 3.41±1.41 | 2.61±.69 | 1.27±.35 | 1.82±.87 |
| U17 | CONTROL | 2.87±1.30 | 1.72±.80 | 1.42±.35 | 1.94±.67 |
| | INDEP | 2.58±1.27 | 2.12±1.01 | 1.42±.29 | 2.20±.59 |
| | DEP | 2.43±1.01 | 1.64±.91 | 1.25±.36 | 2.10±.63 |
| | IMMO | 2.57±1.40 | 1.63±.90 | 1.23±.33 | 2.18±.69 |
| | MOB | 2.37±1.01 | 2.29±1.07 | 1.11±.40 | 2.01±.65 |
| PT's outcome $\chi$(*p*-value) | 5.173(.270) | | | | |
| GKs' outcome $\chi$(*p*-value) | 4.528(.339) | | | | |

Legend: PT – Penalty takers; GK – Goalkeepers

### *3.4.1 Descriptive of the dynamics of the penalty taker-goalkeeper dyads*

Figure 3-2 presents illustrative cases of trials in each condition of this study, describing the goalkeeper-goal line angle and the penalty taker-ball angle over time, for U15 and U17.

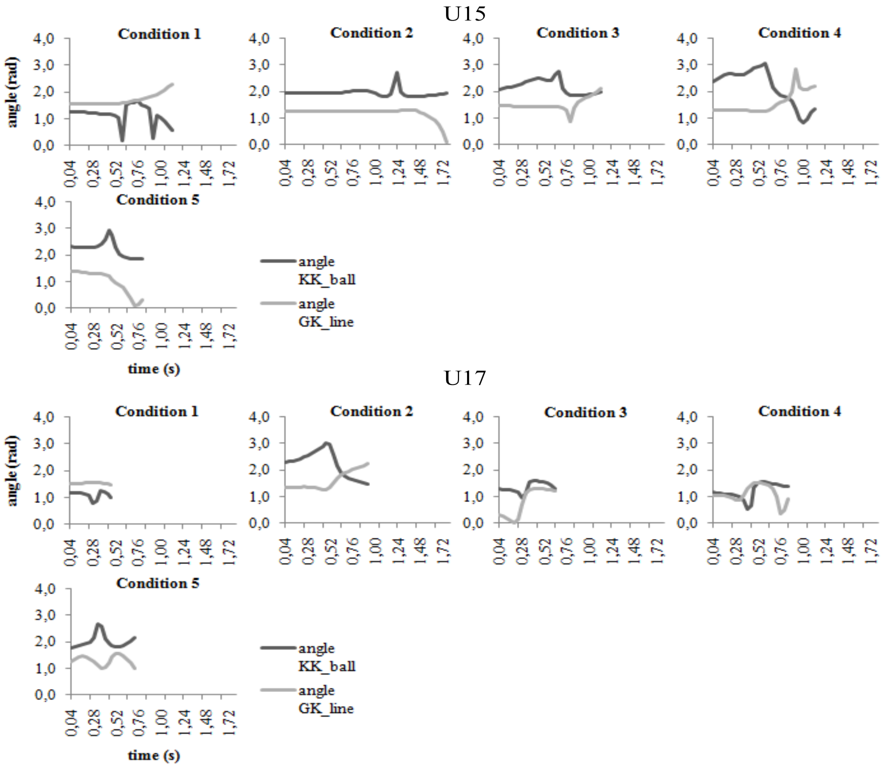


Figure 3-2. Illustrative (exemplar) cases of the angle goalkeeper-goal line and the angle penalty taker-ball along time, in each of the five conditions (one penalty kick per condition), for U15 and U17 groups.

Despite different values and variability in interactions between participants across conditions, some commonalities emerged (Figure 3-2). During the initial interactions of the participants in each dyadic system, both players displayed stable behaviours. In later interactions, abrupt changes (when angular values crossed over or oscillated in different directions) emerged in those system values at a point before foot-ball contact, an observation common to the majority of conditions for both age groups.

### *3.4.2 The interaction age and instructional constraints on performance*

To clarify whether performers organised different movement solutions to adapt to different instructional constraints while obtaining similar performance outcomes (i.e., capturing adaptive variability, a correlation was performed between participants' performance outcomes and their respective process tracing measures (Table 3-2). Inferential statistics for interactions between age and instructional constraints are also summarized in Table 3-2.

Analysis of data in Table 3-2 shows no strong relation between each participant's performance outcomes and their process-tracing measures. A significant main effect for Condition was identified in the movement speed of penalty takers during the run up, $F_{(3.364,141.276)} = 4.589$, $p \leq .003$. Bonferroni's post hoc tests ($p \leq .024$) discriminated differences between the control condition and DEP condition, with higher mean values recorded in the former. Also, the 5 (Condition) x 2 (Age Group) mixed-model ANOVA revealed significant Condition*Age Group interaction effects, $F_{(3.364)} = 3.224$, $p \leq .020$. In analyses of the movement speed of goalkeepers there was a significant main effect for Condition, $F_{(3.497,146.861)} = 5.169$, $p \leq .001$, and no Condition*Age Group interaction effects were identified, $F_{(3.497)} = 1.053$, $p \leq .377$. Post hoc tests revealed differences ($p \leq .003$) between the control and MOBILE conditions, with higher mean values of movement speed in the latter. Statistical analyses of data on the goalkeeper-goal line angle revealed a main effect for Condition, $F_{(3.395,142.594)} = 4.056$, $p = .006$ and no interaction effects in Condition*Age Group, $F_{(3.395)} = 2.315$, $p \leq .071$. Post hoc tests revealed higher angular mean values for INDEP compared to MOBILE conditions ($p \leq .007$). In analyses of the penalty taker-ball angle, no main effect was found for Condition, $F_{(3.289,138.123)} = .946$, $p \leq .427$), nor interaction effects observed for Condition*Age Group, $F_{(3.289)} = .879$, $p \leq .462$.

Age group analyses using mixed-model ANOVAs showed no main effects for Age in the movement speed of penalty takers ($F= 3.558$, $p \leq .066$), and for speed of goalkeepers ($F = .273$, $p \leq .604$), as well as the penalty taker-ball angle ($F = .138$, $p \leq .712$). The only main effect observed for Age Group was for the goalkeeper-goal line angle ($F = 4.394$, $p \leq .042$) with higher angular mean values observed in the U15 group compared to the U17 group. In analyses of performance outcomes, no main effect for Age Group was found for the efficacy of penalty takers ($F = 3.595$, $p \leq .065$) and goalkeepers ($F = 3.595$, $p \leq .065$).

Table 3-2. Correlation between players' outcome and their process tracing measures, divided per Group and Condition and inferential statistics for process tracing measures for Age Group and Condition factors.

| | | *r values* | | | |
|---|---|---|---|---|---|
| Group | Condition | PT outcome/ speed | PT outcome/ angle with the ball | GK outcome/ speed | GK outcome/ angle with goal line |
| U15 | CONTROL | 0.21 | 0.13 | 0.24 | -0.30 |
| | INDEP | 0.12 | 0.17 | 0.29 | -0.14 |
| | DEP | 0.23 | 0.11 | -0.10 | -0.00 |
| | IMMO | -0.02 | -0.04 | 0.00 | 0.15 |
| | MOB | 0.08 | -0.39 | 0.22 | -0.39 |
| U17 | CONTROL | 0.22 | -0.02 | 0.34 | 0.39 |
| | INDEP | 0.17 | 0.19 | 0.04 | -0.10 |
| | DEP | 0.09 | 0.00 | -0.22 | -0.02 |
| | IMMO | 0.23 | 0.00 | 0.14 | -0.51 |
| | MOB | 0.29 | 0.01 | -0.07 | -0.02 |
| p-value | | Mixed-model ANOVA – process tracing measures | | | |
| Group main effect | | .066 | .712 | .604 | .042 |
| Condition main effect | | .003 | .427 | .001 | .006 |
| Condition*Group interaction effects | | .020 | .462 | .377 | .071 |

Legend: PT – Penalty takers; GK – Goalkeepers

## 3.5 Discussion

This study aimed to identify how different instructional constraints imposed on penalty takers and goalkeepers in different age groups of youth footballers influenced outcomes and process-tracing measures of performance. Additionally, we sought to investigate whether some process-tracing measures could reveal a relationship between the interacting performers in the penalty kick. Data illustrated that, at a specific point, and overall instructions followed by penalty takers and goalkeepers, a sudden change in variables occurred, characterised by angular oscillations by both players as they changed their positioning during performance. In the final moments of the penalty kick, when the penalty taker was finishing the run up to the ball, we observed variables converging or diverging from initial identical values which could be indicative of dynamic patterns, characterised by stable states and transitions among them, similar to data reported in previous research by Araújo et al. (2006) in 1v1 basketball sub-phases.

Correlational results presented on Table 3-2 can be interpreted from a movement variability perspective, where players' adaptations to different instructional constraints allowed them to maintain constant performance efficacy levels. As observed in previous studies (Hristovski et al., 2006), these findings legitimise sport performance as a relevant context to study the adaptive movement variability of individuals (Davids et al., 2007).

Interesting effects were observed in process-tracing measures. The Condition and Age Group*Condition analyses showed significant main and interaction effects in the movement speed of penalty takers, with follow-up tests discriminating significantly higher mean values in the control condition than when the penalty takers decided the ball's direction during the run up (DEP condition). Penalty takers tended to reduce their running speed in order to identify possible informational variables from the goalkeeper's actions before deciding the direction of the kick (Fajen et al., 2009). This strategy supports findings of Kuhn (1988) and Van der Kamp (2006) who demonstrated the influence of instructions on ball speed, since one can assume that a lower speed of a penalty taker would lead to differences in momentum and a less powerful kick. These findings are in agreement with data reported by Cordovil et al. (2009) showing how key instructional constraints can significantly modify decision-making processes during performance. Despite the differences in the movement speeds of penalty takers, they did not significantly alter their running trajectories (i.e., angle penalty taker-ball) between conditions and between groups.

A main effect for Instructional Constraint in the angle formed by the goalkeeper and goal line during performance was a curious finding, since despite specific instructions for goalkeepers to move in the MOBILE condition, the goalkeeper-goal line angle value in this condition was smaller than that observed in the INDEP condition. Since experimental task constraints should allow participants to produce unrestricted functional movement behaviours that generate prospective information to guide actions (Dicks et al., 2010a), it is possible that the instruction to move side-to-side by the goalkeepers may have compromised the functional relationship between their movement and perceptual systems (i.e., prospection), inhibiting subsequent diving actions. In these conditions flight time was shorter or there was no dive, only a small movement displacement. Table 3-1 shows that, with the exception of the control condition, younger goalkeepers (U15) always displayed higher mean values in goalkeeper-goal line angles. Since they were not only younger, but also less experienced and smaller in physical stature, U15 goalkeepers probably body-scaled their actions, by diving forward and reducing the angle between the ball and the goal. These findings fit with data reported by Dicks et al. (2010) showing how differences in movement speed of adult goalkeepers tended to constrain the strategies they used to save penalty kicks.

A main effect of Instructional Constraint was identified for movement speeds of goalkeepers. Significant differences in performance were observed between CONTROL and MOBILE conditions, suggesting that the instructional constraint to move along the goal line imposed on the goalkeepers resulted in higher average values of movement speed observed in this condition.

Questions are raised on the influence of instructions on players' action tendencies, especially the capacity of verbal instructions to change players' efficacy through training. This was not the goal of this study and more investigation of these issues is required.

To summarise, this study demonstrated that, although different instructional constraints shaped the emergent spatial-temporal variables of performance, participants maintained similar levels of performance efficacy, underscoring their ability to adapt their actions to differing task constraints. The observed data suggested how neurobiological system degeneracy provides a platform for movement adaptation in response to ever changing task and environmental constraints (Davids, Araújo, Button, & Renshaw, 2007). The fact that experimental design conceived only one trial per penalty taker in each condition is a limitation when interpreting the data. Experimental designs in future research on the penalty kick should include a higher number of trials per penalty taker in each condition, but also, should seek to: (i) define what information sources do players use to guide their actions, and (ii), examine whether different instructions can influence kinematic variables of participants' movements that might correlate with kick direction (Dicks et al., 2010b).

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# 4 Genuine Actions Lead to Genuine Information: the Case of Deceptive and Non-deceptive Penalty Kicks

## 4.1 Abstract

This study addresses the extent to which humans can move so as to disguise their intentions, using the soccer penalty kick as experimental task. Twelve professional and semi-professional players shot to one of the sides of the goal without simulating (non-deceptive condition) or simulating a shot to the opposite side (deceptive condition). Correlation and regression analyses with shot direction as dependent variable were used to determine the usefulness, for goalkeepers' anticipatory behaviour, of aspects of the body kinematics of the penalty takers. Several kinematic variables correlated highly with shot direction, especially those related to the lower part of the body. Some of these variables, including the angle of the non-dominant foot, acquired high correlations at time intervals that are useful to goalkeepers (e.g., 200 ms before ball contact). Compound variables, defined as linear combinations of variables, were found to be more useful than locally defined kinematic variables. Whereas some kinematic variables showed substantial differences in their relation to ball direction depending on deception, other kinematic variables were less affected. Results are interpreted with the hypothesis of non-substitutability of genuine action. The study can also be interpreted as extending the correlation and regression methodology, often used to analyse variables defined at single moments, to the analysis of variables with a strong temporal dimension.

## 4.2 Introduction

In team ball sports such as handball, basketball, or football, there are severe time constraints for athletes while perceiving and acting. In addition, players are pressured to achieve high levels of precision, in part because they have mutually exclusive goals (Abernethy, 1999). A match event in which these constraints on perceiving and acting are particularly evident is the penalty kick in football (Lopes, Araújo, Peres, Davids, & Barreiros, 2008). The penalty kick hence offers an opportunity to study perceiving and acting in a challenging context. One of the aspects of the penalty kick that has received attention concerns the information that goalkeepers use to anticipate the direction of the ball (Diaz, Fajen, & Philips, 2012; Dicks, Button, & Davids, 2010a). With the current experiment we aim to contribute to the knowledge about this aspect of the penalty kick, focusing on the usefulness of informational variables and on the role of deception. Before we describe the goals of the experiment in more detail we briefly review previous results.

A first crucial issue is the time at which goalkeepers commit themselves to a side. As reported by Franks and Harvey (1997), who analysed penalty kicks from FIFA World Cup competitions between 1982 and 1994, the average time from ball contact to the ball crossing the goal line is about 600 ms, and the average movement time for the goalkeeper to reach the location at which the ball crosses the goal line ranges between 500 and 700 ms. It thus becomes clear that goalkeepers who base the direction of the dives on the first part of the ball trajectory are likely to start the dives too late, especially if one takes into account that a small perceptual-motor delay must exist. Dicks, Davids, and

Button (2010) — who analysed slightly less expert players than Franks and Harvey — reported average ball flight times between 590 and 648 ms and average movement times between 750 and 1085 ms. Both the findings reported by Dicks et al. and by Franks and Harvey are consistent with the common claim that goalkeepers should not rely exclusively on information from the ball trajectory.

If goalkeepers want to avoid random dives (and dives based only on previous knowledge of the penalty taker) they must hence rely on the kinematics of the penalty taker before ball contact. Two questions arise. First, which kinematic variables are good predictors of ball direction? And second, which kinematic variables are actually used by goalkeepers? A substantial body of work has addressed the second question, using self-reports (Kuhn, 1988), occlusion paradigms (Dicks, Button, Davids, 2010b; Smeeton & Williams, 2012), and, most particularly, gaze-registration methods (Dicks et al., 2010a; Piras & Vickers, 2011; Savelsbergh, van der Kamp, Williams, & Ward, 2005). Areas that goalkeepers have been claimed to focus on include the penalty takers' hips, the non-dominant (i.e., non-kicking) foot, and the region between the ball and the dominant leg (i.e., 'visual pivot'; Piras & Vickers, 2011).

Less research has concentrated on the for the present study more relevant first question, about how useful the candidate kinematic variables actually are. As mentioned above, Franks and Harvey (1997) analysed videos of penalties in FIFA Word Cup competitions. They concluded that several kinematic variables have a high reliability at ball contact. These variables include the knee angle of the dominant leg and the point of ball contact. However, given the time constraints for goalkeepers, Franks and Harvey considered that variables should be reliably perceivable before ball contact. This led them to consider the final placement (i.e., pointing direction) of the non-dominant foot as the most useful variable. They reported that this variable has a reliability of about 80% and that it can be detected about 150 to 200 ms before ball contact.

Studies by Lees and Owens (2011) and Diaz et al. (2012) also concerned the usefulness of the candidate kinematic variables. These studies are more sophisticated than the one by Franks and Harvey (1997), in the sense that motion capture equipment was used to register the kinematics of the penalty takers, allowing more advanced methods to analyse the reliability of the candidate variables. The three studies (i.e., the ones by Diaz et al., Franks & Harvey, and Lees & Owens) agree in pointing toward the orientation of the non-dominant foot as a relatively reliable source of information around 200-250 ms before ball contact. Lees and Owens also reported hip rotation (as projected on the horizontal plane) and hip and ankle flexion as significant indicators of shot type and shot direction. Diaz et al. presented results for several locally defined kinematic variables. In addition, they concluded that global or distributed information might be useful. At 200 ms before ball contact, for instance, one of the sources of distributed information considered by Diaz et al. had a reliability of 77%. Such an emphasis on distributed information is consistent with research in other sports (e.g., Abernethy, Gill, Parks, & Packer, 2001; Huys, Smeeton, Hodges, Beek, & Williams, 2008; Ward, Williams, & Bennett, 2002).

The experiments reported by Lees and Owens (2011) and Diaz et al. (2012), however, are not without shortcomings. First, penalty takers were asked to shoot the ball into a smaller-than-standard size goal (Lees & Owens) or into a small (2.43-m wide) canvas substituting a goal (Diaz et al.). Second, penalties were shot from a distance shorter than the regular 11 m. And third, no goalkeepers were present during the penalty kicks. The results of these studies can hence be generalized to penalty kicks in match situations only if one assumes that these aspects do not affect the kinematics of the kicks, or, more precisely, if one assumes that they do not affect the usefulness of the considered variables. We think that the importance of this assumption warrants further research. Relatedly, the importance of representative designs has previously been emphasized in penalty kick studies (Dicks et al., 2010a; Lopes et al., 2008; cf. Araújo, Davids, & Hristovski, 2006).

In addition, and related to the main focus of our study, the experimental designs of Lees and Owens (2011) and Diaz et al. (2012) and did not consider the issue of deception, even though deception was mentioned in the respective discussions as being an important issue (cf. Dicks et al., 2010b; Smeeton & Williams, 2012). Imagine that a goalkeeper relies on the orientation of the non-dominant foot. If penalty takers know this, they may try to deceive the goalkeeper by kicking the ball in the opposite direction of that to which the non-dominant foot is oriented. Penalty takers may likewise try to reduce the usefulness of other kinematic variables. Some aspects of the kicking action, however, need to be established in order to kick the ball in a particular direction, meaning that it is likely that some higher-order or distributed kinematic variables remain specific to the kicking direction intended by penalty takers. This is captured by the hypothesis of the non-substitutability of genuine action: In trying to produce an unnatural movement pattern, one may produce some of the kinematic details of the genuine action, but typically not all of the details needed to convince the perceiver that the action is genuine (Farrow, Abernethy, & Jackson, 2005; Richardson & Johnston, 2005; Runeson & Frykholm, 1981, 1983).

To summarize, the combined literature states that goalkeepers' actions are at least partly based on the kinematics of the penalty takers before ball contact. To analyse the usefulness of the available kinematic variables, and to analyse which variables are actually used, it seems indispensable to register the movements of penalty takers during penalty kicks. Useful work in this regard has been done by Lees and Owens (2011) and Diaz et al. (2012), but further advances may be achieved by performing experiments in more representative situations and by considering the issue of deception. We asked professional and semi-professional players to take penalties in a situation with a goalkeeper and with a standard-size goal. The players used deceptive and non-deceptive strategies. The movements of the player were registered with an infrared movement registration system.

A further aspect of our study that we consider a contribution with regard to previous work in the field of penalty kicks is our data analysis, which is inspired by work concerning variable use in other tasks (Jacobs, Runeson, & Michaels, 2001; Michaels & de Vries, 1998). We assess the usefulness of single kinematic variables with the correlations between the kinematic variable and ball direction, reasoning that more useful variables have higher correlations. Likewise, the usefulness of combinations of variables (which may also be referred to as compound variables, higher-order variables, or distributed variables) is assessed with multiple regressions with ball direction as dependent variable. Our application of correlation and regression analysis has the particularity that the values of the information variables in our analyses change continuously during the approach of the penalty takers to the ball. Our analyses therefore extend the use of correlation and regressions analyses from applications with single-moment variables to temporarily extended variables (cf. Michaels, Zeinstra, & Oudejans, 2001). In addition to using ball direction as dependent variable, we performed correlation and regressions using the observed diving direction as dependent variable, aiming to obtain a speculative indication about which variables goalkeepers use.

## 4.3 Methods

### *4.3.1 Participants*

The penalty takers were twelve male professional and semi-professional players from the same team ($M_{age}$= 21.2 years; *SD* = 4.6 years) and the goalkeepers were five young but experienced non-professionals ($M_{age}$= 17.4 years; *SD* = 0.9 years). At the time of the experiment all participants played in the Portuguese National Second Division or in the Portuguese National Junior Second Division. All participants had played six or more consecutive years of competition. Although the goalkeepers belonged to the same club as the penalty takers, they did not have regular training or competitive events with each other. Table 4-1 presents the age, dominant foot, professional status, and competitive category of each player. Informed consent was obtained from the players and from their club, after the ethical approval of the study by a local university committee.

Table 4-1. Participant description.

| | Age | Footedness* | Status** | Category*** |
|---|---|---|---|---|
| Penalty takers | | | | |
| 1 | 26 | R | P | Senior |
| 2 | 29 | R | P | Senior |
| 3 | 17 | R | SP | U18 |
| 4 | 19 | R | SP | Senior |
| 5 | 24 | R | P | Senior |
| 6 | 19 | R | SP | Senior |
| 7 | 16 | L | SP | U18 |
| 8 | 27 | L | P | Senior |
| 9 | 20 | R | SP | Senior |
| 10 | 18 | R | P | U18 |
| 11 | 26 | R | P | Senior |
| 12 | 18 | R | SP | U18 |
| Goalkeepers | | | | |
| 1 | 17 | | A | U18 |
| 2 | 18 | | A | U18 |
| 3 | 16 | | A | U18 |
| 4 | 18 | | A | U18 |
| 5 | 18 | | A | U18 |

Legend: *Handedness: R – Right-footed penalty takers; L – Left-footed penalty takers. **Status: P – Professional player; SP – Semi-professional player; A – Amateur player. ***Category: U18 – Junior (under 18 years old) National 2$^{nd}$ Division players; Senior – players above 18 years old playing in National 2$^{nd}$ Division.

### *4.3.2 Materials*

The experiment was performed indoors with a standard soccer goal (7.32 x 2.44 m). The penalty kick mark was located 11 m from the goal. Judo mattresses protected goalkeepers from injuries. A regular size and weight ball was used. To facilitate the instructions to the penalty takers, two pieces of tissue (1.83 x 2.44 m; one green and one red) were placed at the sides of the goal, immediately after the goal line and 0.12 m from the posts (Figure 4-1).

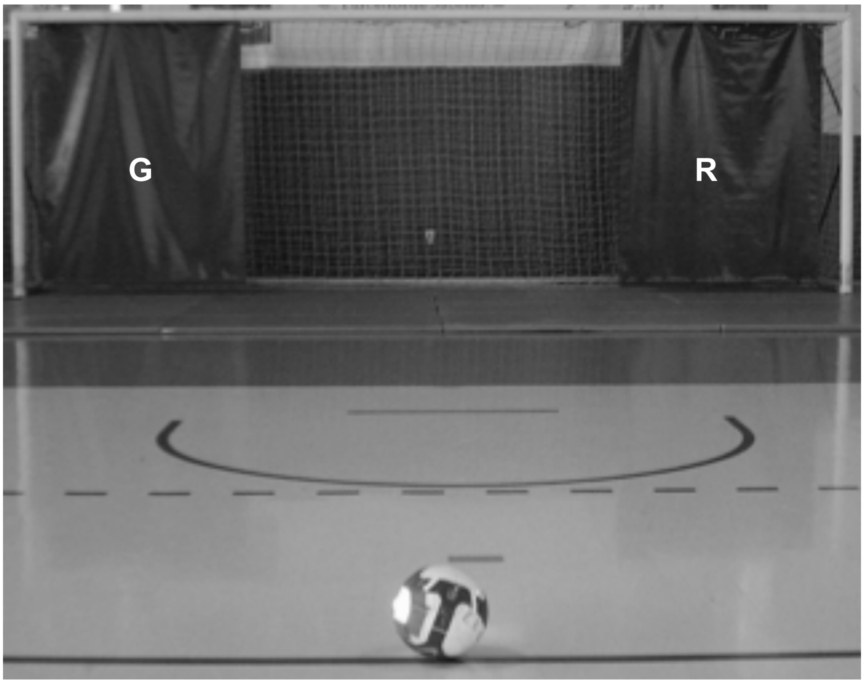


Figure 4-1. Goal used in experiment with green (G) and red (R) target areas. The judo mattresses on the floor protected goalkeepers from dive injuries.

A four-camera infrared system (with the frequency set at 150 Hz) was used to record the kinematics of the penalty takers (Qualisys AB, Gothenburg, Sweden). The experiment was also recorded with a standard video camera (Sony DCR-HC23; 25 Hz). Camera positions are shown in Figure 4-2. The software used for the registration was Qualisys Track Manager 2.3. Penalty takers wore regular soccer shorts (not covering the knees), their own indoor shoes, and a swimming cap. Sixteen lightweight light-reflecting markers with a diameter of 40 mm were used. Ten markers were attached to the skin: on the shoulders, elbows, wrists, hips (posterior superior iliac spine), and knees. Four markers were attached to the shoes: one on the backside of each shoe (moved slightly outwards) and one on the outer side (near the first metatarsal bone). Two markers were placed on the swimming cap: on the back of the head, one left and one right. In addition, a small piece of reflective cloth was attached to the ball. Although the Qualisys systems often captured this piece of cloth as if it were a marker until a few frames after ball contact, this information was not used in our analyses.

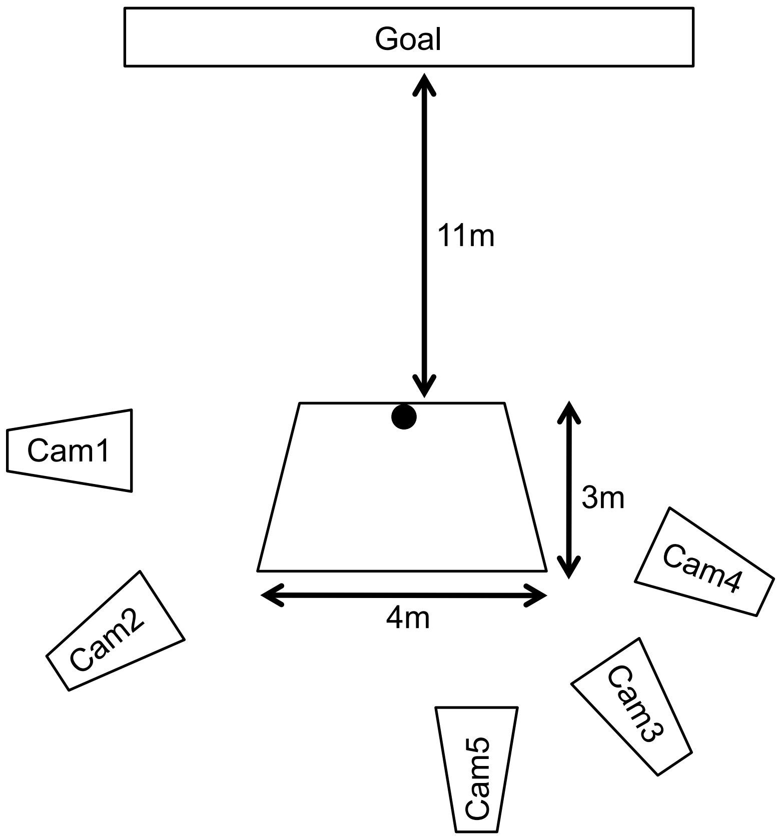


Figure 4-2. Top view of experimental set-up. The trapezoid area around the penalty kick mark (black filled circle) represents the volume covered by the Qualisys cameras (Cam 1, Cam 2, Cam 3, and Cam 4). A standard video camera (Cam 5) recorded the trials from behind the penalty taker. The shown camera positions were the ones used for right-footed penalty takers. For left-footed penalty takers the positions were mirror-reversed.

### *4.3.3 Procedure*

Before the actual experiment participants were asked to warm up. For the penalty takers the warm up included penalty kicks to the experimental target areas (the green and red pieces of tissue). During the experiment each penalty taker performed 60 penalty kicks. Goalkeepers 1 to 5 participated in at least

178, 194, 177, 122, and 35 trials, respectively; for 14 of the 720 trials the participating goalkeeper was not registered. Due to limitations of the volume covered by the motion capture system, a maximum run up distance of 3.5 m was allowed. The design included two independent variables: shot direction (left or right) and strategy (deceptive or non-deceptive). The factorial combination of these independent variables led to the following instructions: (1) "shoot to green without simulating"; (2) "shoot to red without simulating"; (3) "shoot to green but simulate shooting to red"; and (4) "shoot to red but simulate shooting to green". These instructions were given just before each trial. Goalkeepers were not informed about the instructions to the penalty takers. Goalkeepers switched on goal from one penalty kick to the next, waiting for their turn on the sideline. All participants were allowed to rest in self-selected periods.

### *4.3.4 Data analysis*

Data from the infrared movement-registration system were first processed with the Qualisys software. With this software we identified (and named) the 3-dim trajectories corresponding the 16 markers. The trajectories were gap-filled with an algorithm included in the software. All gap-filled trajectories were checked visually. The gap-filled data were exported to MATLAB 9.0 (The Mathworks Inc, Natick, MA, USA). In Matlab, the frame of ball contact was determined with a self-developed algorithm based on the position of the dominant foot. The results obtained with this algorithm were checked visually for each trial.

Values of a substantial number of kinematic variables were computed from 1.5 s (225 frames) before ball contact until 0.5 s (75 frames) after ball contact. We selected the more interesting of these kinematic variables for presentation in this article. Variables selected for presentation include: head angle, shoulder angle, hip angle, dominant foot angle, non-dominant foot angle, dominant foot movement direction, and the approach angle of the penalty taker to the ball (all computed as projected on the ground plane and taken with reference to the axis from the penalty mark to the middle of the goal). Also presented are results for the dominant knee angle (measured as the angle formed by the markers on the hip, knee, and back of the foot) and the dominant foot speed (measured as the speed of the marker on the front part of the dominant foot).

Part of the Results section concerns correlation and regression analyses that aim to determine the relation of the candidate kinematic variables with the horizontal direction of the ball. The correlations and the regression models were computed for each penalty taker and each deception condition, and at each moment in time with respect to ball contact. This means that the parameters of the models were different for different individuals, conditions, and moments in time. For the variables dominant foot speed and dominant knee angle the correlations were expected to be (and found to be) the opposite for left- and right-footed penalty takers (e.g., right-footed players kick faster to the left; left-footed players kick faster to the right). We hence inverted the correlations for these variables for the left-footed penalty takers before averaging the correlations over all penalty takers. For the other variables the expected and observed direction of the correlations was the same for left- and right-footed penalty takers. In addition to relations between kinematic variables and ball direction we analysed relations between kinematic variables and the dive direction of the goalkeeper.

The recordings from the standard video camera were used to code three variables: trial outcome, goalkeeper movement, and ball direction. Outcome was coded as: 1 = ball out of goal or on bars; 2 = goalkeeper stops ball; 3 = goal despite goalkeeper touching ball; and 4 = goal without goalkeeper touching ball. The movement of the goalkeeper was coded as: -1 = dive to the left (as seen from the perspective of the penalty taker); 0 = no dive; and 1 = dive to the right. Only trials with Codes -1 and 1 were included in correlation and regression analyses with dive direction. To determine the ball direction for a particular trial, the video was stopped when the ball crossed the goal line, and the lateral and height coordinates were measured on the screen (Figure 4-3) and converted to real-world measures. Only the lateral direction of the ball was used in the analyses. For trials in which the goalkeepers actually dove to one of the sides, the videos were also used to estimate the time between the initiation of the diving movement and the moment at which the foot of the penalty taker contacted the ball (cf. Dicks et al., 2010b; Dicks et al., 2010).

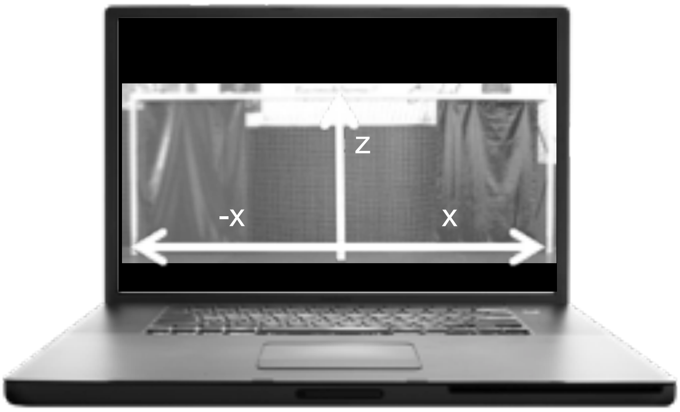


Figure 4-3. Illustration of the lateral (x) and height (z) coordinates of the ball direction, which were obtained through video analyses on a computer screen.

## 4.4 Results

In this section we consider (1) measures concerning penalty kick outcome, (2) correlations between single kinematic measures and penalty kick direction, (3) multiple regressions with several kinematic measures predicting penalty kick direction, and (4) correlation and regression analyses with dive direction as dependent variable.

### *4.4.1 Outcome measures*

Table 4-2 presents the percentages of penalty kicks that missed the goal, were stopped, were touched by the goalkeeper, or were scored without being touched. The percentages are presented overall and for the different deception conditions. On average 67.5% of the penalty kicks were scored, of which 5.6% with the ball being touched by the goalkeeper. The remaining 32.5% of the penalty kicks were not scored, 18.8% due to goalkeeper interception and 13.7% because of being placed outside of the goal or on the bars. To compare the deceptive and non-deceptive instructions' outcome we computed a paired *t* test for each coding category (using the percentages per penalty taker). No significant differences were observed between the two instructions: $t(11)=.99$, $p=.35$ (Code 1: Out); $t(11)= -.27$, $p=.79$ (Code 2: Save); $t(11)= -.56$, $p=.59$ (Code 3: Touch); and $t(11)= -.09$, $p=.93$ (Code 4: Goal). We also compared the sums of Codes 3 and 4—which gives the total percentage of scored penalty kicks—for each penalty taker on the different instructions. This difference was not significant either: $t(11)= -.41$, $p=.69$. Hence, we did not find that instructions concerning deception affected the percentages in these outcome measures.

Table 4-2. Percentage of penalties that fell in coding categories defined in Method section

| | Overall | | | | Deceptive | | | | Non-deceptive | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 Out | 2 Save | 3 Touch | 4 Goal | 1 Out | 2 Save | 3 Touch | 4 Goal | 1 Out | 2 Save | 3 Touch | 4 Goal |
| Penalty takers | | | | | | | | | | | | |
| 1 | 11.7 | 23.3 | 13.3 | 51.7 | 10.0 | 30.0 | 6.7 | 53.3 | 13.3 | 16.7 | 20.0 | 50.0 |
| 2 | 5.1 | 15.3 | 8.5 | 71.2 | 0.0 | 20.0 | 13.3 | 66.7 | 10.0 | 10.0 | 3.3 | 73.3 |
| 3 | 5.0 | 23.3 | 10.0 | 61.7 | 10.0 | 10.0 | 13.3 | 66.7 | 0.0 | 36.7 | 6.7 | 56.7 |
| 4 | 13.3 | 21.7 | 1.7 | 63.3 | 16.7 | 23.3 | 3.3 | 56.7 | 10.0 | 20.0 | 0.0 | 70.0 |
| 5 | 18.3 | 20.0 | 0.0 | 61.7 | 16.7 | 23.3 | 0.0 | 60.0 | 20.0 | 16.7 | 0.0 | 63.3 |
| 6 | 13.3 | 13.3 | 5.0 | 68.3 | 10.0 | 10.0 | 6.7 | 73.3 | 16.7 | 16.7 | 3.3 | 63.3 |
| 7 | 21.7 | 15.0 | 1.7 | 61.7 | 26.7 | 13.3 | 0.0 | 60.0 | 16.7 | 16.7 | 3.3 | 63.3 |
| 8 | 15.0 | 18.3 | 5.0 | 61.7 | 13.3 | 20.0 | 6.7 | 60.0 | 16.7 | 16.7 | 3.3 | 63.3 |
| 9 | 13.3 | 16.7 | 8.3 | 61.7 | 13.3 | 16.7 | 3.3 | 66.7 | 13.3 | 16.7 | 13.3 | 56.7 |
| 10 | 15.0 | 16.7 | 1.7 | 66.7 | 20.0 | 10.0 | 0.0 | 70.0 | 10.0 | 23.3 | 3.3 | 63.3 |
| 11 | 23.3 | 16.7 | 3.3 | 56.7 | 33.3 | 20.0 | 0.0 | 46.7 | 13.3 | 13.3 | 6.7 | 66.7 |
| 12 | 10.0 | 25.0 | 8.3 | 56.7 | 10.0 | 23.3 | 6.7 | 60.0 | 10.0 | 26.7 | 10.0 | 53.3 |
| Average | 13.7 | 18.8 | 5.6 | 61.9 | 15.0 | 18.3 | 5.0 | 61.7 | 12.5 | 19.2 | 6.2 | 62.1 |
| Goalkeepers | | | | | | | | | | | | |
| 1 | 12.4 | 21.3 | 7.3 | 59.0 | 9.9 | 23.8 | 10.9 | 58.0 | 15.7 | 20.2 | 4.9 | 61.5 |
| 2 | 17.0 | 11.9 | 6.7 | 64.4 | 21.2 | 10.5 | 4.8 | 51.8 | 14.4 | 14.6 | 9.5 | 51.8 |
| 3 | 10.2 | 22.0 | 4.5 | 63.3 | 11.5 | 23.7 | 2.7 | 65.3 | 10.0 | 21.8 | 7.7 | 62.9 |
| 4 | 16.4 | 19.7 | 3.3 | 60.7 | 22.2 | 20.3 | 4.9 | 54.9 | 11.0 | 19.9 | 2.3 | 68.9 |
| 5 | 11.4 | 17.1 | 5.7 | 65.7 | 12.5 | 12.5 | 0.0 | 77.8 | 11.7 | 22.8 | 11.4 | 56.2 |
| Average | 13.5 | 18.4 | 5.5 | 62.6 | 15.5 | 18.2 | 4.7 | 61.6 | 12.6 | 19.9 | 7.2 | 60.3 |

Legend: Categories 1 (out) and 2 (save) represent missed penalties and Categories 3 (touch) and 4 (goal) represent scored penalties.

To exclude the hypothesis of random guesses by the goalkeepers when diving, we computed the point-biserial correlation between dive direction (dive left or dive right; excluding penalty kicks without dives) and the horizontal position at which the ball reached the goal line. This correlation was positive and significant: $r_{pb}$=0.24, $p$<.001. Hence, diving directions were better than chance, meaning that, at least to some extent, the dives were based on detected information.

Even though penalty takers were encouraged to rest in self-selected periods, the performance of 60 consecutive penalties may have induced fatigue. It is also possible that learning occurred. To analyse possible effects of fatigue or learning we performed correlations for each penalty taker between penalty kick outcome (scored or not scored) and trial number (1 to 60). The correlations ranged from -.18 to .24 ($M$=.02). None of these correlations reached significance: $p$>.07 for all correlations and $p$>.29 for all but two. We interpret these findings as indicating that trial number was not related to success.

#### ***4.4.2 Single kinematic variables and ball direction***

Figure 4-4 presents the correlations between ball direction and single kinematic variables, for the non-deceptive condition (solid blue curves) and the deceptive condition (dashed red curves). The moment of ball contact is defined as 0.0 s (vertical line segments). The main groups of variables selected for presentation in this figure are: (1) variables with high correlations with ball direction during a time window before ball contact, (2) variables with high correlations at the moment of ball contact, and (3) variables with substantially different correlations in the deceptive and non-deceptive conditions. Before initiating the presentation of the results, it is worth mentioning that in order to be useful as an information source for goalkeepers, a variable should not only be highly correlated with ball direction, but it should be so before a certain moment (after which goalkeepers can no longer use information due to temporal constraints). Remember, from the introduction, that Franks and Harvey (1997) considered 150 to 200 ms before ball contact an appropriate time window.

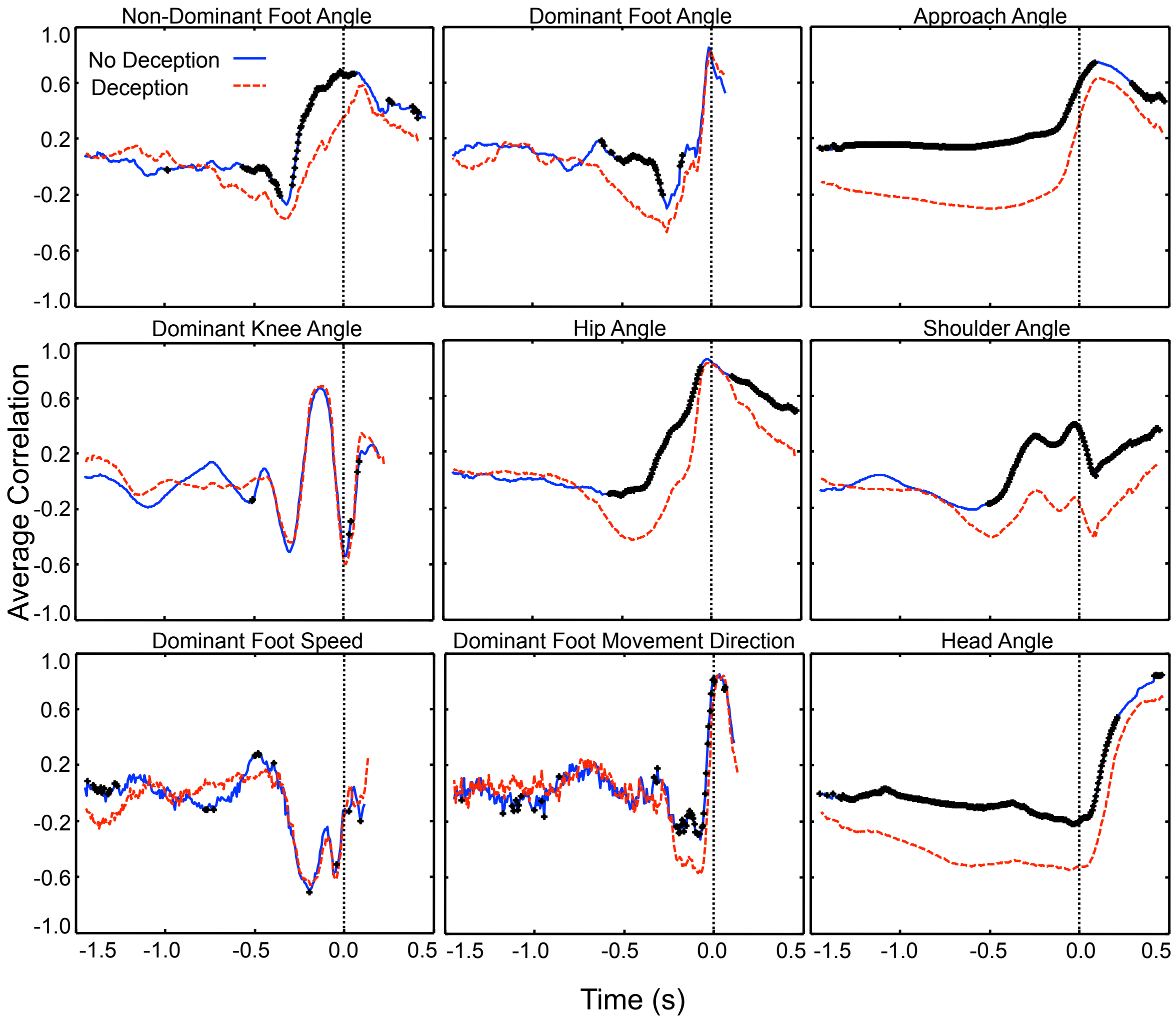


Figure 4-4. Time evolution of correlations between single kinematic variables and ball direction. Curves represent correlations computed per penalty taker and averaged over the twelve penalty takers. Asterisks indicate that the curves differ significantly ($p<.05$, for a $t$ test for paired samples on the $z$ scores of the twelve correlations). The maximum number of penalties per computed correlation was thirty. In the most relevant parts of the curves relatively few markers were lost, meaning that the average number of penalties ($n$) used to compute the correlations was close to thirty. For example, at $t$=-1.0, $n$=28.7 ($SD$=1.9); at $t$=-0.5, $n$=29.3 ($SD$=1.1); and at $t$=0.0, $n$=29.0 ($SD$=1.9). Curves are not shown if for one (or more) of the penalty takers the number of valid trials was less than ten.

A general inspection of Figure 4-4 indicates that earlier than about 0.5 s before ball contact, the relations between our candidate kinematic variables and ball direction were weak or nonexistent. This was true for both deception conditions. Among the kinematic variables selected for presentation, non-dominant foot angle, dominant knee angle, and dominant foot speed (leftmost column in figure) showed highly positive or negative correlations a certain time window before ball contact. Kinematic variables that showed high correlation values at the moment of ball contact were: dominant foot angle, hip angle, and dominant foot movement direction (middle column in figure).

Regarding the influence of deceptive and non-deceptive strategies, the kinematic variables approach angle, shoulder angle, and head angle were found to be affected, as evidenced by the differences between the blue and red curves in the rightmost column of the figure (together with the asterisks indicating that the difference between the curves was significant). Other variables that were affected by deception were the non-dominant foot angle, dominant foot angle, and hip angle. In contrast, dominant knee angle and dominant foot speed were not substantially affected by the penalty taker’s strategy. For the variables that correlated most highly with ball direction at the moment of ball contact (middle column), one may observe that the blue and red curves lie close to each other at the moment of ball contact. This indicates that although the deception affected these variables before ball contact, it did not do so at ball contact.

Having presented the usability potential and susceptibility to deception of single kinematic variables, with correlational analyses, the next subsection explores these issues for compound variables through multiple regressions.

### *4.4.3 Compound kinematic variables and ball direction*

Figure 4-5 presents results of regression analyses with ball direction as dependent variable. Multiple correlations are given by black curves and correlations of individual kinematic variables by colored curves. Regressions for the non-deceptive and deceptive conditions are presented in the left and right column, respectively. The following groups of kinematic variables were considered (from top to bottom in the figure): (1) variables with high individual correlations during a time window before ball contact, (2) variables with high individual correlations at the moment of ball contact, (3) variables with substantially different correlations in the deceptive and non-deceptive conditions (i.e., the ones susceptive to deception), and (4) all previously considered highly correlating variables (i.e., taking the variables from categories '1' and '2' together).

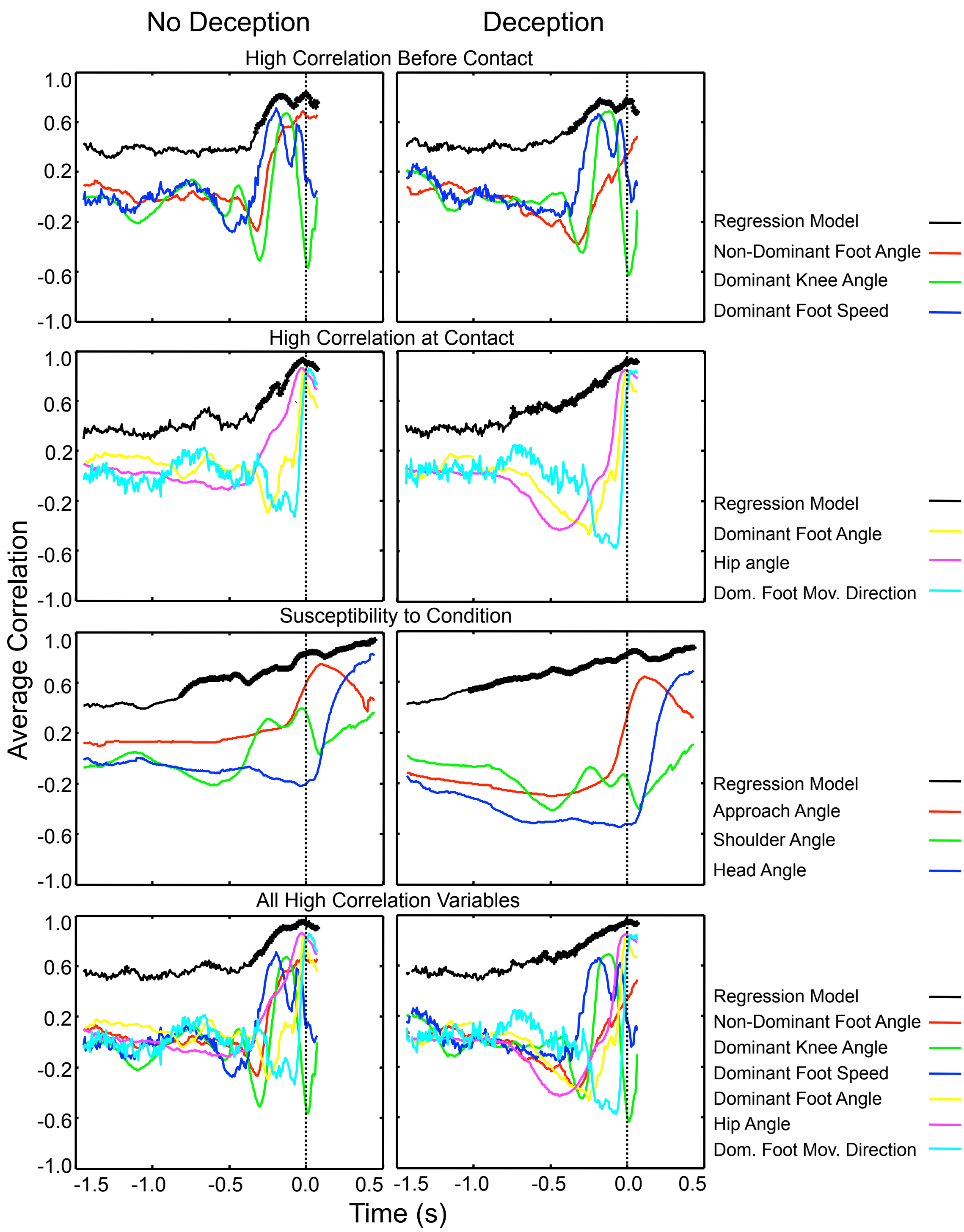


Figure 4-5. Multiple correlations associated with regression models with ball direction as dependent variable together with the correlations of the individual variables included in the respective regression models, as a function of time. For each panel and each moment in time, the regression analyses were computed per penalty taker and then averaged over all penalty takers. Asterisks indicate that the regression model was significant for at least 7 penalty takers. The curves for the dominant foot speed were positive-negative inversed for illustration purposes, allowing a better visualization of its contribution to the multiple correlations. A trial was not included in the analysis if one of the variables had a missing value (e.g., because one of the relevant markers was not registered). Curves are presented only if the regression analyses for each penalty taker were computed with at least 10 valid trials. To give an indication

of the average number of trials (*n*) used to compute these curves: for *t*=-1.0, *n*=27.8 (*SD*=2.9); for *t*=-0.5, *n*=29.2 (*SD*=1.1); and for *t*=0.0, *n*=28.3 (*SD*=2.8).

An overall examination of Figure 4-5 reveals three trends. First, in many cases the multiple correlations fluctuated at an approximately constant level of about 0.5 until about 0.5 s before ball contact, after which they increased to reach values of about 0.8 or 0.9 at ball contact. In the later part of the approach the majority of regression models were significant (as indicated by the asterisks). Second, the black curves often lie substantially higher than the colored ones, indicating that compound variables defined with several of the individual variables are in many cases better predictors of ball direction than the individual variables by themselves. Third, comparing the black curves in the left and right panels indicates that the multiple correlations were not substantially affected by deception. The lack of a strong effect of deception on the multiple correlations is noteworthy especially for the third row of panels, because the variables in these panels were selected precisely because as individual variables they were affected by deception.

#### *4.4.4 Kinematic variables and dive direction*

Although our experiment was designed to analyse the relation between kinematic variables and ball direction, it also allows us to tentatively analyse the relation between kinematic variables and dive direction (analysed as a binary variable: either left or right), and, thereby, to illustrate how correlation and regression analyses may be used in this regard. Figure 4-6 gives the correlations associated to analyses that regress dive direction against two groups of kinematic variables: the three variables that showed high correlations with ball direction before ball contact (left panels) and all six variables that showed high correlations with ball direction, either before or at ball contact (right panels).

If a goalkeeper systematically detects and uses information from a particular moment during the approach, then one would expect the correlations between dive direction and the kinematics to be high and significant at that moment. One may hence suspect on the basis of the Figure 4-6 that Goalkeeper 1 used information detected earlier in the approaches than the other goalkeepers. The figure also seems to point to differences in which variables were used. For instance, especially as judged from the left panels, the non-dominant foot angle (red curve) seems to have an important contribution to the highest multiple correlations for Goalkeeper 2, which can be observed around ball contact. This, on the other hand, does not seem to be as much the case for Goalkeepers 3 and 4, even though these goalkeepers also show their highest correlations around ball contact.

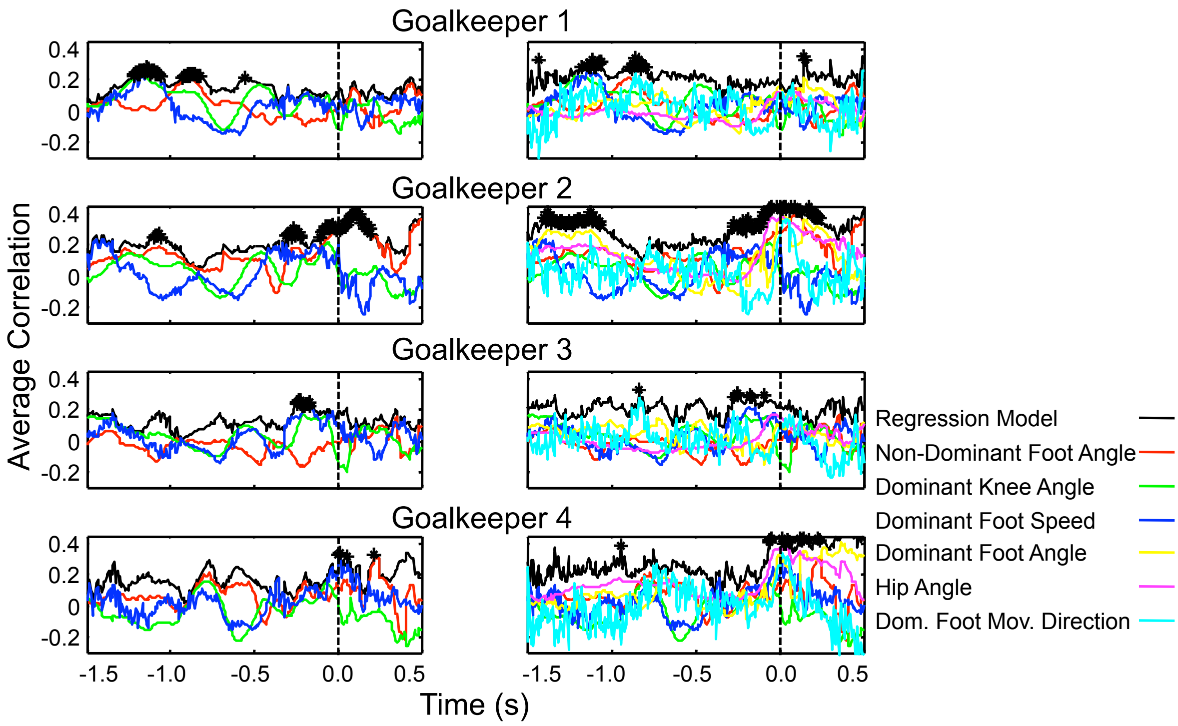


Figure 4-6. Multiple correlations associated with regression models with ball direction as dependent variable together with the correlations of the individual variables included in the respective regression models, as a function of time. For each panel and each moment in time, the regression analyses were computed per penalty taker and then averaged over all penalty takers. Asterisks indicate that the regression model was significant for at least 7 penalty takers. The curves for the dominant foot speed were positive-negative inversed for illustration purposes, allowing a better visualization of its contribution to the multiple correlations. A trial was not included in the analysis if one of the variables had a missing value (e.g., because one of the relevant markers was not registered). Curves are presented only if the regression analyses for each penalty taker were computed with at least 10 valid trials. To give an indication of the average number of trials ($n$) used to compute these curves: for $t$=-1.0, $n$=27.8 ($SD$=2.9); for $t$=-0.5, $n$=29.2 ($SD$=1.1); and for $t$=0.0, $n$=28.3 ($SD$=2.8).

Motivated by the tentative prediction, on the basis of Figure 4-6, that Goalkeeper 1 may detect information from an earlier part of the approach than the other goalkeepers, we estimated and analysed the initiation time of the diving movements. The initiation times for Goalkeepers 1 to 4 were -0.69, -0.25, -0.49, and -0.39 s, respectively. A one-way analysis of variance (ANOVA) showed that the effect of goalkeeper on movement initiation time was significant, $F(3, 525) = 275.0$, $p<.001$, and Tukey post hoc tests showed that all goalkeepers differed significantly from all others ($p<.001$). Hence, consistent with the prediction from Figure 4-6, Goalkeeper 1 seemed to initiate the dives earlier.

### *4.4.5 Percentages of correctly predicted left-right directions*

Some previous work has presented results about the usefulness of kinematic variables as the percentage of correctly predicted left-right directions per variable (e.g., Diaz et al., 2012; Franks & Harvey, 1997). To facilitate the comparison of our results to previous results we also computed such percentages. Figure 4-7 shows these percentages for the regression analyses with ball direction as dependent variable and the three variables with high individual correlations before ball contact as predictors. The predicted percentages are based on a cut-off value: if the values of a predictor are higher than the cut-off value, then a penalty to right is predicted, and if the value of the predictor is lower than the cut-off value, then a penalty to the left is predicted. We computed the cut-off values that maximized the differences between the percentage of correctly predicted directions and the chance level (50%). Qualitatively, the percentage curves (Figure 4-7) are similar to the corresponding correlation curves (upper panels of Figure 4-5). Percentages higher than 90% are observed toward the end of the approaches.

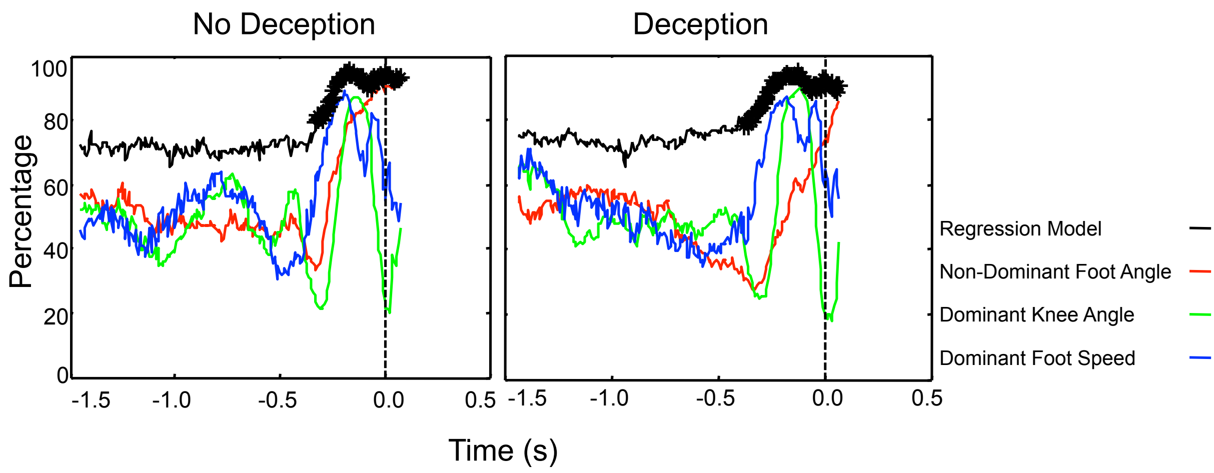


Figure 4-7. Percentages of correctly predicted left-right ball directions associated to regression models and individual kinematic variables. Percentages were computed with cut-off values that were optimized so as to make the presented percentages as different as possible from 50%. Asterisks indicate that the regression model was significant for at least 7 penalty takers.

## 4.5 Discussion

The present study used the penalty kick situation to address the related issues of deception and the usefulness of informational variables. The more detailed aims of the study were (1) to determine the usefulness of single kinematic variables, related to the movement of penalty takers, as predictors of the direction of the penalty kick, (2) to determine the usefulness of compound kinematic variables, and (3) to determine the effect of deception on the usefulness of these kinematic variables. In contrast to previous studies (Diaz et al., 2012; Lees & Owens, 2011), our experiment was performed with a regular-size goal and with a goalkeeper. We analysed the usefulness of individual variables with correlational analyses and the usefulness of compound variables with regression analyses (cf. Jacobs et al., 2001; Michaels & de Vries, 1998).

Kinematic variables that were found to be useful about 200 ms before ball contact include the non-dominant foot angle, dominant knee angle, and dominant foot speed. Kinematic variables that were found to have a high correlation at ball contact include the dominant foot angle, hip angle, and dominant-foot movement direction. Hence, our findings indicate that the most highly correlating variables are related to the kinematics of the lower part of the body.

The finding that the non-dominant foot angle is useful before ball contact is consistent with the findings of Lees and Owens (2011) and Diaz et al. (2012). Our result replicates this finding in a situation that is more representative to a match situation (Araújo et al., 2006). The precise form of the usefulness curves for this variable in our study, however, is different from the one reported by Diaz et al. In our study the correlations associated to this variable increase until ball contact (upper left panel of Figure 4-4; see also red percentage curves in Figure 4-7). In the study of Diaz et al., the reliability shows a peak around 250 ms before ball contact and then decreases (see the curve associated to the foot yaw of the non-kicking foot in their Figure 3a).

Kinematic variables that, in our experiment, were affected by deception include the approach angle, shoulder angle, and head angle (right column of Figure 4-4), and also the non-dominant foot angle and hip angle. To give a tentative summary of these findings, one could say that the variables most affected by deception are the ones that are not related to the kinematics of the lower part of the body, and that the ones that are least affected by deception are the ones related to the dominant leg.

Several variables showed a trend from being affected by deception before ball contact to not being affected by deception at ball contact. This can be interpreted with the hypothesis of non-substitutability of genuine action

(Richardson & Johnston, 2005; Runeson & Frykholm, 1981, 1983). While trying to accomplish a particular goal (i.e., left or right direction of the ball), penalty takers can act in such a way that (local) aspects of their body movements are less correlated with ball direction. However, as the action unfolds toward the moment of ball contact, the inability to perform completely deceptive actions becomes evident. Whatever movement penalty takers perform when trying to deceive, they cannot avoid that some fundamental aspects of the kinematics must reflect the genuine action (i.e., the one that fits their intention).

Relatedly, our regression analyses showed that compound variables (or combined, higher order, or distributed variables) are often more useful than individual kinematic variables, and that compound variables are almost equally useful in deceptive and non-deceptive conditions. Hence, despite the attempted deception, the regression analyses revealed the intention of the penalty takers. The usefulness of compound variables beyond local kinematic variables is consistent with the emphasis on distributed information by Diaz et al. (2012; cf. Huys, Cañal-Bruland, Hagemann, Beek, Smeeton, & Williams, 2009; Huys et al., 2008). This implies a warning for research that considers only local kinematic variables (e.g., Lees & Owens, 2011): Such research may not be able to reveal the full information potential that is available to the perceiver. Note in this regard that the human perceptual system has repeatedly been claimed to rely on distributed information (e.g., Abernethy et al., 2001; Gibson, 1979; Ward et al., 2002).

Our analyses applied correlation and regression methods to analyse informational variables whose values continuously changed over time, hence extending previous applications of such analyses to variables defined at single moments (e.g., Michaels & de Vries, 1998). A more speculative part of the analyses showed how correlation and regression analyses can be applied to analyse which variables are used by goalkeepers. Individual differences in variables use were observed, which is consistent with studies that addressed variable use with other tasks (Jacobs & Michaels, 2001; Withagen & van Wermeskerken, 2009). Relatedly, one might expect that improvements in the performance of goalkeepers may go together with changes in which variables they use, and that knowledge about which variables they use may facilitate the design of more effective practice conditions (Beek, Jacobs, Daffertshofer, & Huys, 2003; Chow, Davids, Hristovski, Araújo, & Passos, 2011; Ibáñez-Gijón, Travieso, & Jacobs, 2011).

It is appropriate, however, to include a few critical remarks at this point. First, whereas the main part of our analyses was based on twelve penalty kickers, the analyses on variable use included only four goalkeepers. This is not sufficient to confirm the usefulness of the methodology and to generalize the results to a broader population. Second, penalty takers were instructed beforehand to which side of the goal to shoot. This means that diving early to one side did not include the risk that the penalty taker would react and shoot to the other side. Although the goalkeepers were not informed about this part of the procedure, we cannot rule out that they may have noticed this novel constraint in the course of the experiment and that they may have adapted their performance accordingly (cf. Lopes, Araújo, Duarte, Davids, & Fernandes, 2012). Third, judged from the category of their respective leagues, the level of expertise of the goalkeepers was not as high as the one of the penalty takers. On the positive side, the experimenters judged the motivation of the goalkeepers to be exceptionally high. As junior players they were excited to play against the professional and semi-professional players of the first team of their own club.

In conclusion, and reminding the aims of this study, our claims are: (1) highly correlating sources of local information can be found especially in the penalty takers' lower body, (2) sources of distributed information can be identified with regression models and their potential to predict ball direction is often superior to the predictive potential of local variables considered individually, and (3) despite the fact that penalty takers are able to conceal their intention to some extent, most particularly early in the approach, for several kinematic variables the deception is unsustainable at the final moments before ball contact, where players have to act genuinely in order to accomplish the intended goal.

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# 5 The Importance of Height After Side: The Vertical Direction of Penalty Kicks and its Influence on Performance

## 5.1 Abstract

The present work analyses how the height of penalty kicks in association football is related to the probability that goalkeepers stop the ball. The work also addresses the relation between ball height and the movement kinematics of the penalty taker. The analysed data correspond to a previously ran experiment for which, so far, only results concerning the lateral shot direction have been reported. In the experiment, twelve professional and semi-professional players shot 60 penalties each; to target areas on the left and right sides of the goal, in deceptive and non-deceptive conditions, and with natural variation in shot height. The present work shows that low and height penalties are less likely to be stopped by goalkeepers than penalties shot at middle heights. Correlation and regression analyses with shot height as dependent variable were applied to identify kinematic variables that relate to ball height. Dominant foot height and dominant foot pitch were most highly correlated with ball height. In contrast, the forward-backward inclination of the trunk of the kicker was not found to be related with ball height. It is argued that penalty takers' performance variability is relatively low as compared to the variability in other types of kicks because of constraints inherent to the penalty kick. Future manipulations of task features are mentioned as plausible paths to deepen knowledge about the kinematic predictors of ball height.

## 5.2 Introduction

In association football, after a ball is kicked with the purpose to score a goal, the goalkeeper's probability to avoid that outcome is highly dependent — among several other issues, such as his/her displacement capacity and body stature (Dicks, Davids, & Button, 2010), or wind conditions — on two physical properties of the shot: the speed and direction of the ball. In what concerns ball speed and its dependence on the kicking kinematics, a vast body of research has been produced from the 1960's (Roberts & Metcalf, 1968; Isokawa & Lees, 1988) until nowadays (Andersen & Dorge, 2011; De Witt & Hinrichs, 2012). Skill level, approach speed, and kicking foot speed are all related to ball speed (Lees, Asai, Andersen, Nunome, & Sterzing, 2010). However, for the present study, the most relevant property of the kick is ball direction, and specifically, the relations between kicking height and efficacy and between kicking height and the penalty takers' body kinematics.

Historically, research has focused on specific kinematic characteristics of the kicking action, and the trunk angle is a commonly accepted critical feature of the kicking technique (for a review see Lees et al., 2010). Lees and Nolan (2002) reported backward lean values of the kick of 12º and 0º at ball contact for two professional players in a maximal instep kick. For collegiate level players, Orloff, Sumida, Chow, Habibi, Fujino, et al. (2008) reported backward lean values of 3º and 13º in males and females, respectively. Moreover, it is widely accepted at a coaching level that kickers should lean forward or backward depending on whether they want to direct the ball in a lower or higher direction. Furthermore, based on scientific literature (Shan & Zhang, 2011), coaching recommendations specifically advise to place the supporting foot adjacently (i.e., side-by-side) to the ball, because, by placing the foot behind the ball, kickers are argued to produce an ascendant shot, instead of a low-to-the-ground one. Despite these links between body kinematics and kicking height, investigation still needs to substantiate such claims for a specific kind of kick such as the penalty kick.

Association football encompasses different types of kicks that cannot be disconnected from their aims. Considering the array of possible kicks (e.g., goal kick, free kick, corner kick, or any other kick resulting from individual or collective actions during the game), the penalty kick represents a particular case in what concerns the possible maximum height that allows accomplishing the purpose of the kick. The task constraints (Araújo, Davids, & Hristovski, 2006) dictate that, regardless of the penalty takers' movement variability during the run up, they need to kick the ball with an angle of approximately 0-11º (i.e., the angular range defined by the segment that unites the penalty kick mark with the goal bar and the ground surface; see Figure 1). This means that, as compared to other kicks (with angles that can at least go up to 16º; Asai, Nunome, Maeda, Matsubara, & Lake, 2005), penalties have to be performed with relatively standardized movement features at/or around ball contact. Consider, as example, the offset distance relatively to ball's centre of mass. Whereas this offset can go to very low values for other kicks (i.e., the ball is kicked below its centre of mass which implies a high shot; Asai et al., 2005), in the penalty kick this value cannot be so low, because penalty takers risk to send the ball above the goal bar.

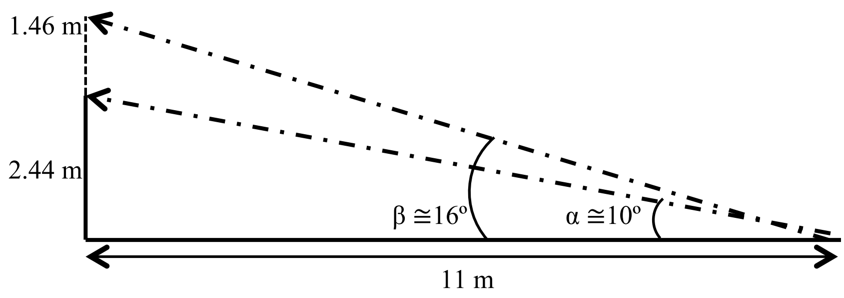


Figure 5-1. Ball projection angles of two different types of kick plotted in the penalty kick scenario. Projection angle (α ≅10º) in the penalty kick taking into account goal height (2.44 m). A predicted ball height (3.9 m, i.e., 2.44 + 1.46 m) is calculated taking into account a maximum projection angle (β ≅16º) obtained in a kick with an offset (i.e., the height of foot-ball contact point, relatively to the height of ball's centre of mass; see Asai et al., 2005) of -20 mm.

Additional reasons to expect reduced variability in the penalty taker's movements as compared to kickers involved in other types of kick are: 1) penalty takers normally kick the ball with a relatively constant speed (about 20-24 m/s; van der Kamp, 2006; cf. Teixeira, 1999) and 2) the distance that penalty kicks cover (11 m) is short and constant. With respect to this second point one should note that the kinematics of kicks are highly dependent on the horizontal distance that a kick has to cover (e.g., maximal kicks involve larger final steps than sub-maximal ones; Lees & Nolan, 2002). The comparison between the penalty kick and other types of kicks (e.g., kicks with a broader range of possible heights such as a goal kick, or even on kicks to a moving target, such as a corner kick, where teammates might compensate an inferior accuracy by moving towards the ball’s landing area) also indicates that the possible range of actions is more restricted for penalty takers than for other kickers. The low variability in the kinematics of penalty kicks related to ball height is further illustrated by goalkeepers reports assuring that it is harder to predict the vertical direction of the ball than the horizontal one (McMorris & Colenso, 1996).

The inclusion of the vertical component of ball direction in research on kicking kinematics has often been done for kicks other than the penalty kick and/or in an indirect way (i.e., with a main purpose other than to study the relation between the kinematics and the vertical direction of the ball). Teixeira (1999) used two targets (0.4 x 0.4 m and 4 x 3 m) to test the effect of different levels of required accuracy on the kinematics of the kick. Linthorne and Patel (2011) investigated the vertical angle that maximizes the distance achieved in a punt kick by the goalkeeper. A previous study on the relation between the vertical direction of the ball and the kickers’ kinematics was conducted by Prassas, Terauds, and Nathan (1990). These authors reported a difference for skilled players performing low and high kicks at the point where the ball is contacted, with higher ball contact points corresponding to lower kicks and vice-versa. The difference in the backward lean of the trunk for the high and low kicks did not reach significance (although it was in the expected direction: 17º and 13º, respectively, for the high and low kicks). Given the lack of significance, this finding cannot be taken as support for the coaching recommendation that, in order to kick a higher ball, the trunk should be leaning backwards while the opposite should be the case for lower kicks. Nevertheless, and sustaining coaching proposals, Williams and Burwitz (1993) associated penalty kicks directed to higher goal areas with a backward leaning of the trunk, whereas a forward leaning of the trunk, combined with head and shoulder movements over the ball, was associated to lower goal locations. Despite these interesting approaches to the analysis of the relation between players' kinematics and the vertical direction of the ball, the kinematic variables that determine the ball's vertical direction in the penalty kick are yet to be identified (Dicks, Button, & Davids, 2010).

In sum, the success of an association football kick strongly depends on two intrinsic properties: the speed and direction of the ball. A large body of research has examined the kinematics of the kickers that influence the first property, but a lack of research is still evident for the second property, and, more notably, for the specific case of the vertical direction of the penalty kick. For the penalty kick, more work has been done on the capacity of the kinematics to predict the horizontal direction of the ball (Diaz et al., 2012; Franks & Harvey, 1997; Lees & Owens, 2011), and valuable work on the vertical direction of the ball has mainly been done with other kicks (Linthorne & Patel, 2011; Prassas et al., 1990; Teixeira, 1999). The analysis of the vertical component of the penalty kick is important because it has been demonstrated that this component exerts an influence on penalty kick outcome (Bar-Eli & Azar, 2009), with more scored penalty kicks at higher areas than at medium ones. Hence, the present study aims 1) to determine the influence of ball height on the outcome of the penalty kick, and 2) to test the relation between the height of the kicks and variables defined in the kinematics of penalty takers. We use data of an experiment reported in this thesis, extending that analyses — which considered the horizontal direction of penalty kicks — with analyses on the vertical direction.

In the analysed experiment, professional and semi-professional players took penalties with a standard size goal, a standard distance, and facing a goalkeeper. The movements of the players were registered with movement registration equipment. In the present study we assess the strength of the relation between single kinematic variables and the vertical direction of the ball with correlations between the kinematic variables and the height of the ball at the goal line. Likewise, the potential of combinations of variables (which may also be referred to as compound variables) is assessed with multiple regressions with ball height as dependent variable. Let us briefly describe the analysed experiment (a more detailed description can be found on chapter 4 of this thesis.

## 5.3 Methods

### *5.3.1 Participants*

Twelve male professional and semi-professional players from the same team ($M_{age}$= 21.2 years; *SD* = 4.6 years) and five non-professional goalkeepers ($M_{age}$= 17.4 years; *SD* = 0.9 years) participated in the experiment. At the time of the experiment, all participants played in the Portuguese National Second Division or in the Portuguese National Junior Second Division.

### *5.3.2 Materials*

The experiment was performed indoors. Two pieces of tissue (1.83 x 2.44 m; one green and one red) were placed at the sides of the goal, immediately behind the goal line and 0.12 m from the posts (Figure 2a). The experiment was recorded with a four-camera infrared system (Qualisys AB, Gothenburg, Sweden) and a standard video camera (Figure 2b). The infrared system recorded sixteen markers. Ten markers were attached to the skin: on the shoulders, elbows, wrists, hips (posterior superior iliac spine), and knees. Four markers were attached to the shoes: one on the backside of each shoe (moved slightly outwards) and one on the outer side (near the fifth metatarsal bone). Two markers were placed on the swimming cap at the back of the head, on the right and left sides.

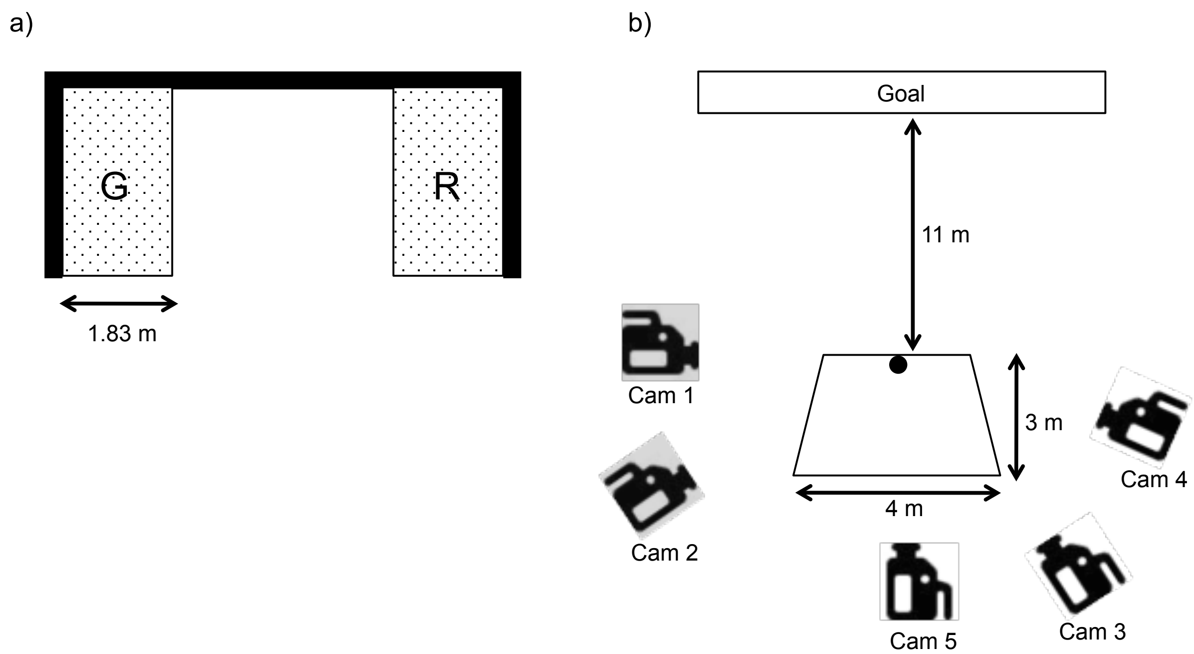


Figure 5-2. Experimental scenario top-down perspective. (a) Goal used in experiment with green (G) and red (R) target areas. (b) The trapezoid area around the penalty kick mark (black filled circle) represents the volume covered by the Qualisys cameras (Cam 1, Cam 2, Cam 3, and Cam 4). A standard video camera (Cam 5) recorded the trials from frontal perspective. The shown camera positions were the ones used for right-footed kickers. For left-footed kickers the positions were mirror-reversed.

### *5.3.3 Procedure*

During the experiment each penalty taker performed 60 penalty kicks, with a maximum run up distance of 3.5 m. The design included two independent variables: shot direction (left/green or right/red) and strategy (deceptive or non-deceptive). The factorial combination of these variables led to the following instructions: (1) “shoot to green without simulating”; (2) “shoot to red without simulating”; (3) “shoot to green but simulate shooting to red”; and (4) “shoot to red but simulate shooting to green”. These instructions were given just before each trial. No instructions were given with respect to the height of the penalties.

### *5.3.4 Data analysis*

Values of a substantial number of kinematic variables were computed from 1.5 s before ball contact until 0.5 s after ball contact. The selection of variables for presentation in this article was based 1) on literature findings relating the variables with the vertical direction of the ball in other types of kicks and 2) on coaching recommendations related to kicking technique and the control of ball height. The variables that were selected for presentation are: the dominant foot height (i.e., the height of the marker on the front part of the foot; cf. Asai et al., 2005; Prassas et al., 1990), the dominant foot speed (i.e., the speed of the marker on the front part of the foot; cf. Lees et al., 2010), the dominant foot angle (i.e., the smallest angle between the floor and the imaginary line connecting the dominant foot markers; cf. Diaz et al., 2012), the non-dominant foot distance (i.e., the horizontal distance between the marker on the front part of the foot and the imaginary line that is parallel to the goal line and that crosses the penalty kick mark), the shoulder-hip-wrist angle for the dominant foot side (i.e., the angle formed at the shoulder by the imaginary lines from shoulder marker to wrist and hip markers, respectively; cf. Lees et al., 2010, for a review on the importance of the arms-trunk relation), and the trunk angle (i.e., the angle between a vector orthogonal to the floor and the segment from the middle between the two hip markers to the middle between the two shoulder markers).

The correlations and the regression models that were computed for these candidate kinematic variables, with ball height as dependent variable, were computed for each penalty taker and at each moment in time (with respect to ball contact). This means that the parameters of the models were different for different individuals and moments in time. To determine the vertical direction of the ball for a particular trial, the standard video was stopped when the ball crossed the goal line or when the goalkeeper contacted it, and the vertical coordinate was measured on the screen (Figure 3). The total height of the goal when projected on the screen was 7.5 cm; the vertical direction of the ball in centimetres on the screen was categorized as ‘low’ = [0.1, 2.5], ‘medium’ = [2.6, 5], and ‘high’ = [5.1, 7.5].

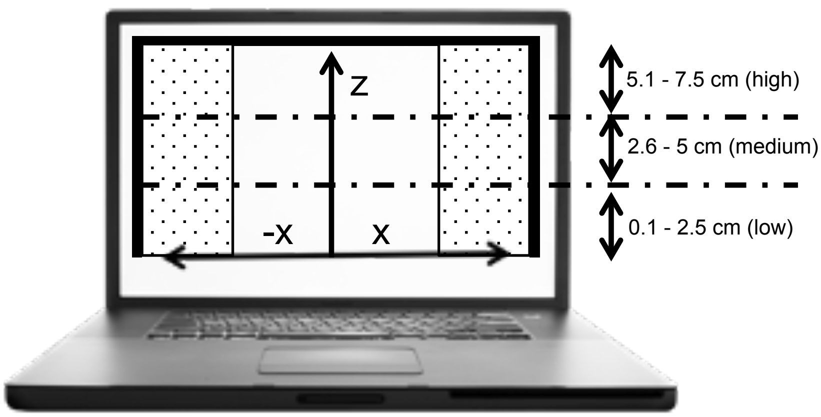


Figure 5-3. Illustration of the horizontal (x) and vertical (z) coordinates of the ball direction, which were obtained through video analyses on a computer screen. The horizontal dashed lines represent the intervals for ball height categories.

## 5.4 Results

In this section we consider (1) the distribution of penalty kicks for different vertical direction and outcome categories, (2) the correlations between single kinematic variables and the vertical direction of the penalty kicks, and (3) multiple regressions with several kinematic variables predicting the vertical direction of the kicks.

### *5.4.1 Distribution of and outcome for different vertical directions*

Table 1 presents the percentage of penalties, for each penalty taker and averaged over all penalty takers, that fell in each of the vertical direction categories. The number of trials in each category is also shown (bottom row of table). Overall, 31.3% of the penalties fell in the ‘low’ category, 36.0% in the ‘middle’ category, and 32.7% in the ‘high’ category. A chi-square test was applied, showing a significant association between the vertical direction of the ball and penalty taker: $\chi^2(22, N=638) = 40.74$, $p = .009$. Verification of the adjusted residuals showed that Penalty Takers 7 and 8 had a frequency above expected on ‘high’ penalty kicks (residuals of 2.0 and 3.2, respectively), whereas Penalty Takers 9 and 11 had frequencies above expected on ‘low’ penalty kicks (residuals of 2.2 and 2.9, respectively). Finally, Penalty Taker 8 showed a number of ‘low’ penalty kicks inferior to the expected value (residual = -3.5).

Table 5-1. Percentages of Penalties per Vertical Direction Category.

| | Ball Height | | |
|---|---|---|---|
| | Low | Medium | High |
| Penalty Taker | | | |
| 1 | 34.0 | 35.8 | 30.2 |
| 2 | 23.7 | 43.6 | 32.7 |
| 3 | 35.1 | 42.1 | 22.8 |
| 4 | 26.9 | 38.5 | 34.6 |
| 5 | 33.4 | 31.2 | 35.4 |
| 6 | 38.6 | 38.6 | 22.8 |
| 7 | 26.8 | 28.6 | 44.6 |
| 8 | 9.8 | 37.3 | 52.9 |
| 9 | 44.1 | 30.5 | 25.4 |
| 10 | 27.1 | 35.4 | 37.5 |
| 11 | 50.0 | 25.0 | 25.0 |
| 12 | 25.9 | 44.4 | 29.7 |
| Average | 31.3 | 36.0 | 32.7 |
| *n* | 200 | 230 | 208 |

Next, the outcome of the penalties was added to the analysis, in terms of goal or no goal. Table 2 presents the percentages of penalties for each of the vertical direction categories separated for outcome. A chi-square test showed that ball height and outcome are associated variables: $\chi^2(2, N=638) = 24.40$, $p < .001$. Scored penalty kicks were above expected for ‘high’ penalties (residual = 4.1), whereas scored penalties were below expected for ‘medium’ penalties (residual = -4.5). Given these results, it becomes important to clarify the reasons for which the ‘medium’ category registered more than the expected number of missed penalty kicks. For this purpose, the outcome variable was considered in three categories: 1 = save; 2 = goal despite goalkeeper touching ball; and 3 = goal without goalkeeper touching ball. The result of a chi-square test was: $\chi^2(4, N=638) = 45.83$, $p < .001$. Saves by goalkeepers were particularly frequent for the ‘medium’ category (residual = 6.3). This finding was further supported by an analysis that included only the subset of the trials in which the lateral ball direction and goalkeeper's dive direction were identical. In this case the chi-square test showed that: $\chi^2(4, N=364) = 54.09$, $p < .001$, with an adjusted residual of 6.5 for saved penalty kicks at medium ball height.

Additional analyses were performed focusing on the saved penalty kicks (Code 1). The numbers of saved penalty kicks for the 'low' ($n$=33), 'medium' ($n$=77), and 'high' ($n$=19) categories were taken as a percentage of the number of penalty kicks directed to each of these height categories (200 for 'low', 230 for 'medium', and 208 for 'high'). As shown in the bottom row of Table 2, the percentage of saves seems higher for penalty kicks with a 'medium' height (33.5%) than for 'low' and 'high' penalty kicks (16.5 and 9.1%, respectively).

Table 5-2. Percentages of Penalties per Vertical Direction Category Separated for Goal and No Goal.

| | Ball Height | | | | | |
|---|---|---|---|---|---|---|
| | Low | | Medium | | High | |
| | Goal | No Goal | Goal | No Goal | Goal | No Goal |
| Penalty Taker | | | | | | |
| 1 | 33.3 | 35.7 | 33.3 | 42.9 | 33.3 | 21.4 |
| 2 | 26.1 | 11.1 | 41.3 | 55.6 | 32.6 | 33.3 |
| 3 | 32.6 | 42.9 | 39.5 | 50.0 | 27.9 | 7.1 |
| 4 | 23.0 | 38.5 | 38.5 | 38.5 | 38.5 | 23.0 |
| 5 | 38.9 | 16.6 | 27.8 | 41.7 | 33.3 | 41.7 |
| 6 | 34.1 | 53.8 | 38.6 | 38.5 | 27.3 | 7.7 |
| 7 | 21.1 | 38.9 | 21.1 | 44.4 | 57.8 | 16.7 |
| 8 | 12.8 | 0.0 | 23.1 | 83.3 | 64.1 | 16.7 |
| 9 | 47.6 | 35.3 | 31.0 | 29.4 | 21.4 | 35.3 |
| 10 | 33.3 | 0.0 | 25.7 | 77.8 | 41.0 | 22.2 |
| 11 | 54.3 | 38.5 | 17.1 | 46.2 | 28.6 | 15.3 |
| 12 | 28.2 | 20.0 | 30.8 | 80.0 | 41.0 | 0.0 |
| Average | 32.1 | 27.6 | 30.7 | 52.4 | 37.2 | 20.0 |
| *n* (%) | 153 (24.0) | 47 (7.4) | 149 (23.3) | 81 (12.7) | 177 (27.7) | 31 (4.9) |
| *n* (%) of saves | 33 (16.5) | | 77 (33.5) | | 19 (9.1) | |

### 5.4.2 *Single kinematic variables and the vertical direction of the penalty kicks*

As shown above, a significantly poorer efficacy was registered for penalties directed to medium heights. It was also shown that this lower efficacy was mainly caused by a more successful performance of the goalkeepers. In order to find variables in the kinematics of the penalty takers that covary with the vertical direction of the penalties, and that may hence be used to distinguish shots to the more successful and less successful areas, we next address the correlations between ball height and the candidate kinematic variables.

The correlations are presented in Figure 4. Each panel gives the results for one kinematic variable. The moment of ball contact is defined as 0.0 s (and indicated in the figure with the dashed vertical line segments). Asterisks indicate a significance level of $p<.05$. This significance level was obtained with $t$ tests computed on (the Fisher $z$ transformations of) the correlations for each kicker and for the considered variable, hence testing whether the correlations differed from zero. An examination of Figure 4 indicates that earlier than about 0.1 s before ball contact, the relations between individual kinematic variables and the vertical direction of the ball were weak or non-existent. Around the moment of ball contact, the kinematic variables that correlated with the vertical direction of the ball were the dominant foot height and the dominant foot angle (left column in the figure). The correlations for these variables differed significantly from zero in that period.

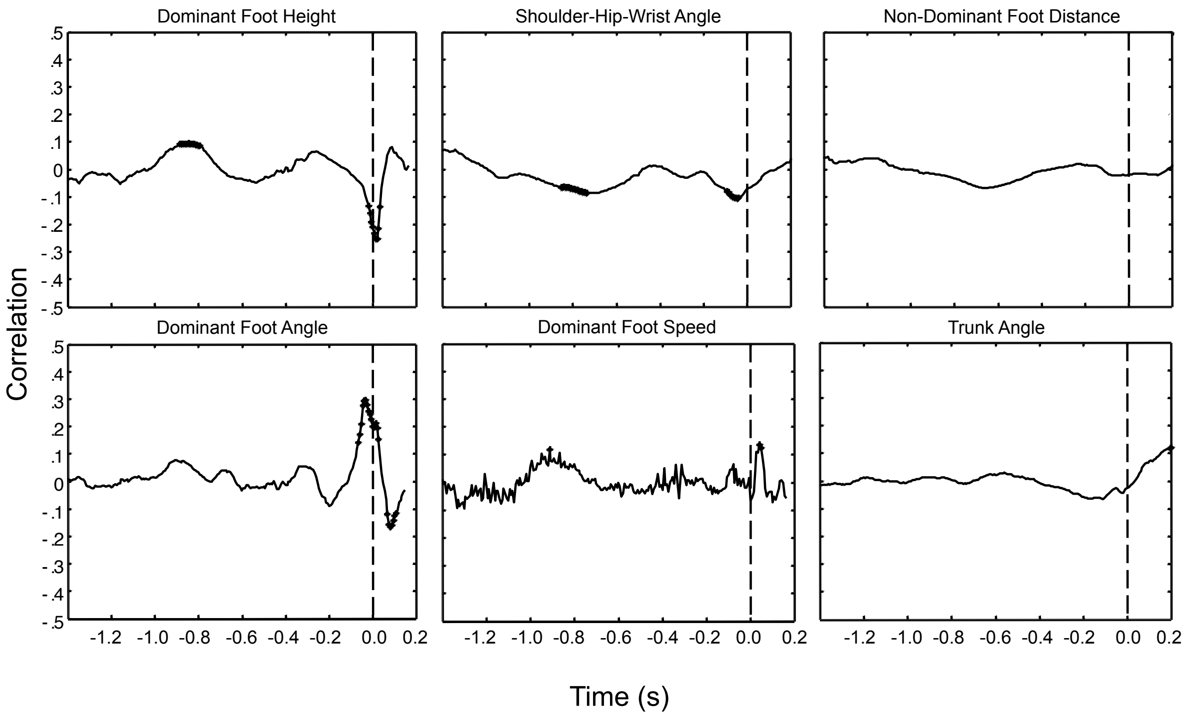


Figure 5-4. Time evolution of correlations between single kinematic variables and the vertical direction of the ball. Curves represent correlations computed per penalty taker and averaged over the twelve penalty takers. The maximum number of penalties computed per correlation was sixty. Curves are not shown if for one (or more) of the penalty takers the number of valid trials was less than ten. Asterisks indicate significance (see text for detail).

The other variables that can be found in the literature and/or are often suggested by coaches and that were included in the analysis did not show substantial correlations with the vertical direction of the ball (centre and right columns in the figure). The correlations for these variables reached significance only occasionally.

Having presented the capacity of single kinematic variables to explain the vertical direction of the ball, the next topic explores the best-fitting linear combinations of these variables through multiple regressions, in order to check the relation of distributed variables and ball height.

### *5.4.3 Multiple regression models and the vertical direction of the penalty kicks*

Figure 5 presents results of regression analyses with the vertical ball direction as dependent variable. Multiple correlations are given by black curves and correlations of individual kinematic variables by coloured curves; asterisks indicate that the regression models were significant for the majority of kickers (i.e., for seven or more of them). Following results presented in Figure 4, the first regression presented in Figure 5 (upper left panel) includes the individual variables with significant correlations around ball contact. The multiple regressions demonstrate that one can see an increment in the correlation values only around ball contact, as was the case for the individual correlations. Moreover, the regression models tended to be significant only around that moment. When other variables were added to the initial two (see the other panels of the figure), a small increase in the correlations is observed. Of these models, the one with the highest multiple correlations around ball contact (close to 0.5) is the one that includes the three variables related to the dominant foot: height, angle, and speed.

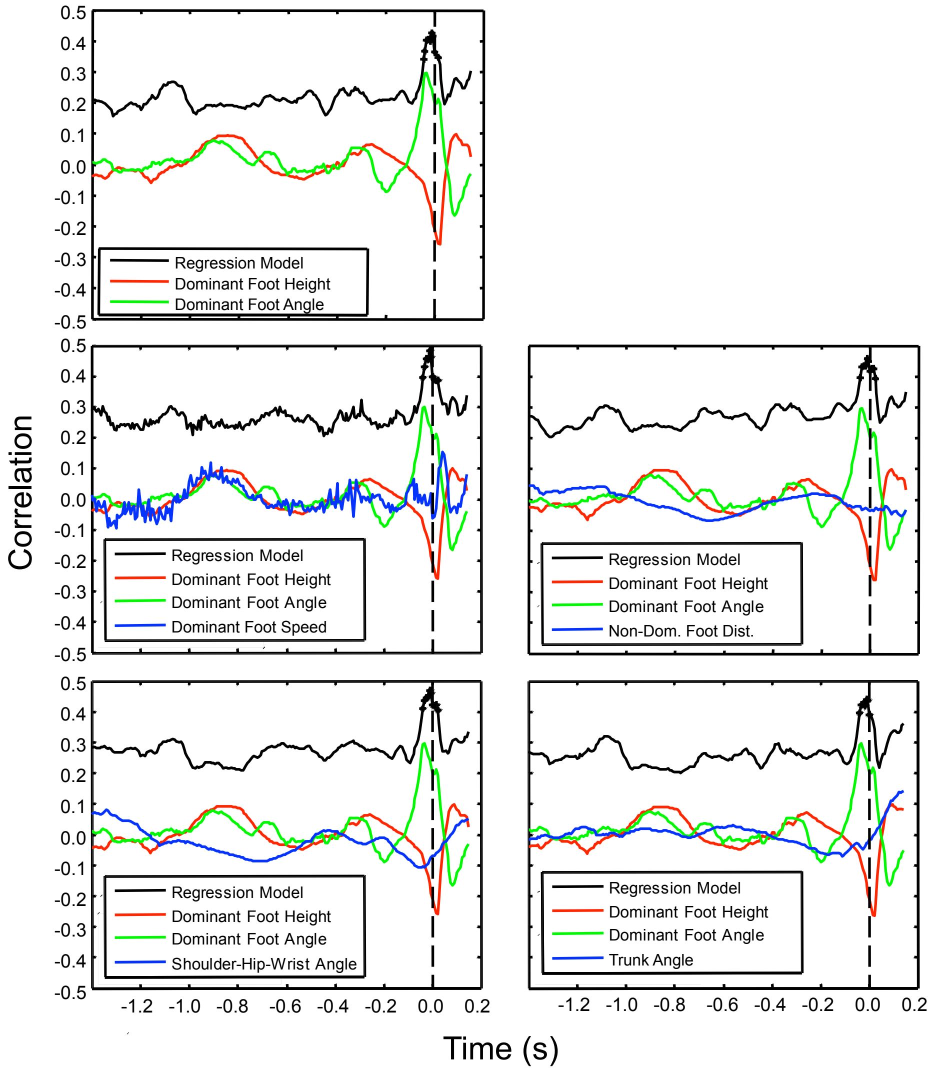


Figure 5-5. Multiple correlations associated with regression models with vertical ball direction as dependent variable together with the correlations of the individual variables included in the respective regression models, as a function of time. For each panel and each moment in time, the regression analyses were computed per penalty taker and then averaged over all penalty takers. Asterisks indicate that the regression model was significant for at least 7 penalty takers. Curves are presented only if the regression analyses for each penalty taker were computed with at least 10 valid trials.

## 5.5 Discussion

This investigation analysed, first, to what extent performance of goalkeepers in the penalty kick situation is affected by variation in ball height, and second, how individual and compound variables of the penalty takers' kinematics relate to ball height in that situation.

A first key issue to consider was the preference of penalty takers in what concerns the height of the kick. Although penalty takers were constrained on the lateral direction of the ball (i.e., they were asked to hit the green or red 1.83-m wide pieces of tissue at the left or right of the goal), they were unconstrained in what concerns ball height, because the pieces of tissue covered the entire goal height (i.e., 2.44 m). We found that the percentages of penalties directed to the different height categories were: 31.3% to the low level, 36.0% to the medium level, and 32.7% to the high level. When considering penalty takers individually, most of them showed a distribution of the penalty kicks over the three levels similar to the averages for those levels (with the exception of Penalty Takers 2, 7, 9, and 11). This distribution is different from the one reported by Bar-Eli and Azar (2009), who analysed 311 penalty kicks from professional leagues from different countries and from championships of national teams. Our results are different particularly at the upper height, where Bar-Eli and Azar registered only 12.9% of the kicks. The same study reported that the majority of penalty kicks (56.6%) were directed to the lower goal area, which is also different from our findings. Bar-Eli and Azar reported that 30.4% of the penalties were directed to the middle area.

Individual results from our penalty takers (Table 1) further illustrate these differences. For the lowest category, none of our penalty takers reached the value reported by Bar-Eli and Azar (2009), and Penalty Taker 8 did not even reach 10%. For the medium category only two penalty takers (7 and 11) showed values lower than the one reported by Bar-Eli and Azar. All our participants directed substantially more penalties to the higher goal areas as compared to the value reported by Bar-Eli and Azar. These differences may relate to the following: although our findings are based on 638 valid trials, we analysed only 12 penalty takers (six professionals and six semi-professionals), whereas Bar-Eli and Azar collected data from championships with top clubs and national teams. In addition, all our participants were members of the same team, whereas the analyses of Bar-Eli and Azar included only the most expert penalty taker(s) of the teams (i.e., the ones responsible for taking penalties during actual matches).

When success is considered, Bar-Eli and Azar (2009) calculated the probability that goalkeepers save penalty kicks for the three vertical direction categories. Expressed in percentages, these values were of 19.8%, 12.6%, and 0.0% for the low, medium, and high directions, respectively. Our results were again different from the ones of Bar-Eli and Azar: we found 16.5% of saves for ‘low’, 33.5% for ‘medium’, and 9.5% for ‘high’ (Table 2). Thus, as compared to the numbers reported by Bar-Eli and Azar, are results show more saves for medium and high penalties.

We next investigated which kinematic variables from the penalty takers’ movements are related to the vertical direction of the penalty kicks. When considered individually, dominant foot height and dominant foot angle were the only variables that presented moderate correlation values with the height of the ball. The negative correlation between dominant foot height and vertical ball direction indicates that the higher the foot the lower the ball direction, as stated in the literature for this variable (Asai et al., 2005; Prassas et al., 1999). In what concerns dominant foot angle, results indicated that a superior angular value corresponds to a higher ball direction (cf. Diaz et al., 2012). With regard to the other individual variables: (1) dominant foot speed showed no relation with ball height, which can be explain by the fact that this variable is normally associated to the exit speed of the ball (Lees et al., 2010), and, as stated by Van der Kamp (2006), regardless of whether a ball is kicked to higher or lower goal areas, it is so at a relatively constant speed in the penalty kick; (2) although the relation between trunk and arms is important according to standard ideas about kicking technique (Lees et al., 2010), in our experiment an association between shoulder-hip-wrist angle and ball height was not demonstrated.

Another often-commented individual kinematic variable is the trunk angle. Although relevant for ball height on isolated kicking (Orloff et al., 2008) and commonly accepted by coaches as a critical feature when training the kicking action, trunk angle was not shown to be related to ball height in our experiment. Explanations of this finding could be based on the fact that the vertical angular range that may lead to success in the penalty kick is narrower than in other types of kicks, such as goal kicks, corner kicks, or free kicks (Asai et al., 2005). Moreover, one cannot neglect that the relation between trunk angle and ball height is not unambiguously supported in the literature, which includes reports with an absence of significant differences for this variable between high and low kicks (Prassas et al., 1999). Even in direct free kicks — where scoring is normally the task goal — the greater distance to the goal allows a superior vertical angular success range, because the longer trajectory allows additional flight time which may reduce the ball height to less than the required 2.44 m. This might allow kickers to lean backward with higher angular values.

When the capacity of two or more variables to explain the vertical ball direction was considered, dominant foot height and dominant foot angle together better predicted ball height than each variable considered individually. Although existent, the correlation values were not very high; they were substantially lower, for instance, than the correlations for the horizontal direction reported in Lopes et al. (2012). The present results should therefore be interpreted with caution if one intends to generalize findings and state these variables as reliable predictors for the penalty kick task. The association of a third variable slightly increased the correlation values in the models. The more explicit case (i.e., the one where correlation reached its highest value) is the dominant foot speed. The best predicting kinematic variables thus were the ones related to the dominant foot.

To our knowledge, this was the first study to examine the relation between the kinematics of penalty takers and the vertical ball direction. Although we have been able to associate some kinematic variables to ball height, the constraints imposed on penalty takers' actions in the standard penalty situation reduce the vertical angular range of the trajectories that may lead to success and, relatedly, these constraints reduce the kinematic variability as compared to other types of kicks (Lees et al., 2010). This made it more difficult for us to identify the kinematic variables related to ball height. In order to remove some of these limitations and thereby to highlight other aspects of the movement-kinematics/ball-height relation, several modification may be useful to consider in future research; one may, for instance, (1) reduce the standard (i.e., 11 m) distance to the goal, hence increasing the angular range that leads to success, or (2) perform experiments without goalkeeper in order to observe the penalty takers' kinematics when performing without speed constraints.

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# 6 General Discussion

This thesis contributed to a better understanding of how informational constraints are explanatory of the penalty kick performance, on representative experimental designs. An ecological dynamics approach explains how performer-environment system variables measured during performance characterize the interaction between penalty taker and goalkeeper.

In this final Chapter, the main findings from this research are presented and discussed. Hence, based on those conclusions, future research paths will be proposed, in order to enhance understanding about the perception-action processes that guide the movement of the players in the penalty kick.

## 6.1 Overview

Chapter 2 clarified the importance of the penalty kick on today's match final score. Through a substantial growth in the research dedicated to its analysis, there is an increase in the empirical knowledge on the penalty kick performance. Ecological dynamics is proposed as an appropriate framework to integrate research key findings. According to this approach, information is the key for understanding action regulation and its dynamics in penalty kick performance. Investigators should consider, not only which information sources are most relevant in the penalty kick, but also how constraints can change, stress or disguise that relevant information and how their consequences are expressed in players' behavioural dynamics. Such an approach would serve to capture the information-based control of the actions of both players in representative design of the penalty kick (Araújo et al., 2007).

Literature already highlighted the influence of different instructional constraints on movement organisation and performance outcome of the penalty kick (Bowtell et al., 2009; Van der Kamp, 2006). Chapter 3 showed how different instructions constrained participants' movements during performance, although the performance outcome remained constant. The coupled behaviour between penalty taker and goalkeeper demonstrated that players on their decisions use information from opponent's actions. The relevance of that action for the final outcome of the penalty kick was not considered though. That relevance was approached on Chapters 4 and 5.

Chapters 4 and 5 showed how the movements of the penalty takers comprise information that specifies ball's horizontal and vertical directions. On Chapter 4, it was observed that the local variables highly correlated with ball horizontal direction are located mainly in the penalty takers' lower body portion, although the information that better predicts ball direction is distributed across different body regions. Moreover, it was found that, despite the fact that penalty takers are able to conceal their intention to some extent, most particularly early in the approach, the deception is unsustainable at the final moments before ball contact, where players have to act genuinely in order to accomplish the intended goal.

Chapter 5 investigated in what extent could the kinematics of penalty takers predict ball height in successful penalty kicks. The analysis of the relation between the vertical direction of the ball and the outcome of the penalty kick showed results that were in contradiction with the literature (Bar-Eli & Azar, 2009). In this case, goalkeepers were more successful in stopping penalty kicks directed to the middle height of the goal than those that were directed to lower or higher heights. Two particular kinematic variables (dominant foot height and dominant foot pitch angle) were correlated with the vertical direction of the ball. Although other variables were not individually correlated, they contributed to an increase in the predictive capacity of the regression models when integrated in the models. Regression models were found to be more useful than individual variables. When defining vertical ball direction, it is proposed that penalty takers' performance variability is narrowed due to the specific task and individual constraints inherent to goal height (2.44 m).

## 6.2 The role of instructional constraints on the movements of the players

Recent research (e.g., Dicks et al., 2010a,b) showed the importance of studying penalty kick in a context that reproduces the features towards which investigation intends to generalize its findings. However, there is still a lack of results based on data obtained through the interaction of players in a representative experimental setting (i.e., regular pitch dimensions and goal dimensions).

Even though players may intend to apply a predetermined strategy when performing (e.g., keeper-independent by penalty taker, or a goalkeeper's predefinition of diving side), the ongoing penalty kick performance could entail a shift on that strategy. The manipulation of these strategies represents a crucial issue to understand the interaction between players (see Bakker et al., 2007;

Cordovil et al., 2009). Performance of both participants seems to be specifically susceptible to different instructional constraints. The mutual dependence between performers was evidenced on the convergence/divergence of some biophysical variables at the last moments of the penalty takers' run up (e.g., goalkeepers' diving angle and penalty takers' run up angle). These features somehow suggest that penalty kick possesses characteristics from dynamical systems, such as stable states and transitions among those states (Araújo et al., 2006). The concept of degeneracy (Edelman & Gally, 2001) is proposed as an explanation for movement adaptation and efficacy levels maintenance, despite the ever-changing task and environmental constraints (Davids et al., 2007).

## 6.3 Penalty taker-environment system's information predicts penalty kick direction

Anticipatory skills are of paramount importance for penalty kick successful action. This means that the ability to detect the information that allows anticipating opponent's action is a major issue for investigation in the penalty kick. Since the intentions of the players are expressed by their actions (Runeson & Frykholm, 1983), investigation should try to identify the information sources from players' movements that are related with their intended goals. Moreover, this investigation assumes crucial relevance, in the sense that the information that specifies action is unequivocal (i.e., not susceptible to deceptive action). The first study demonstrated that the variables that better predict the horizontal direction of the ball were mainly located in the lower part of penalty takers' body. An opposite tendency was identified on the variables most affected by deceptive actions of penalty takers, which were found to be more related with upper body areas. Still on deception, it has been demonstrated, that, although some variables were susceptible to deception on moments prior to ball contact, they were not at ball contact. This finding supported the hypothesis of non-substitutability of genuine action (Richardson & Johnston, 2005), enhancing that penalty takers may try to recreate a movement as authentic, but at some point they will not be able to reproduce all parts of the original (i.e., genuine) movement.

The finding that distributed information is a better predictor of ball direction than local information corroborates the conclusions of Diaz et al. (2012). This also implies that investigation that only considers local predictors (e.g., Lees & Owens, 2011) has to be cautiously generalised, since penalty takers could be able to deceive the informative capacity of some local predictors by changing other body parts. This supposition is in line with previously stated capacity of players for movement adaptation and the maintenance of efficacy levels.

After studying lateral direction of the ball, it became important to deal with the second component of ball direction, i.e., its height. As far as we know, vertical direction of the ball in the penalty kick was not considered in the literature for analysis in a time continuous basis, (see Bar-Eli & Azar, 2009; Zhou & Inomata, 2009 for notational analysis). Results showed that goalkeeper's efficacy is dependent of the height of the ball, with a superior number of saves at the middle height of the goal. Hence, it seems that goalkeepers save more penalty kicks around medium height, than on lower and upper parts of the goal. This assumption is somehow reasonable, since middle height is the closest to goalkeepers' initial position. Dominant foot height and dominant foot pitch angles were the variables most related with the vertical direction of the ball. Although other kinematic variables were not individually correlated, they seemed to contribute to increase the predictive capacity of regression models. Nevertheless, contrary to the lateral direction of the ball, these results should be interpreted with caution. Whereas in lateral direction, the models clearly lie higher than individual variables (e.g., Chapter 4, third row of figure 5), this is not the case on the vertical direction of the ball. A possible reason for a higher value of the model could be related with the parameter fitting in the regression. When searching for the best linear combination of variables, it is likely that any variable (and not necessarily the ones here applied) could improve the models bust by fitting to the regression, and not because a real contribution to the model was given.

## 6.4 Conclusions

This thesis concluded that strategies performed by players could affect theirs and opponents' movements on the penalty kick. Analysis of players' interaction showed that penalty kick can be observed as a dynamical system, as already demonstrated on other sports tasks (Araújo et al., 2006). Moreover, despite the influence of strategies on players' movements, performers were able to keep their efficacy levels, showing that degeneracy (Edelman & Gally, 2001) is a key concept, describing the capacity of both penalty taker and goalkeeper to adapt to the constant environmental changes.

We also studied which parts of penalty takers' body are informative about both horizontal and vertical directions of the ball when penalty kicks are performed under deceptive and non-deceptive conditions. As suggested in previous research, both local (Franks & Harvey, 1997; Lees & Owens, 2011) and distributed (Diaz et al., 2012) information sources were found to be reliable predictors of the intentions of the penalty takers, while other body regions were differently related with ball direction according to each deception condition. Notwithstanding this deceptive capacity of penalty takers, ultimately (i.e., at the last moments before foot-ball contact) there are some characteristics of movement that link it to the intention of the performer, which is expressed by the principle of genuine action (Richardson & Johnston, 2005). In what concerns the association between penalty takers' kinematics and ball height, future experimental sets should address the manipulation of specific penalty kick features in order to analyse in more detail which information sources define ball vertical direction in the penalty kick.

## 6.5 From theory to practice

This body of work evidenced how information sources represent a decisive role on the process and outcome of the penalty kick. In order to improve players' performance in the penalty kick, investigators and coaches must create research and training conditions that promote the adjustment of performers to relevant features of the opponents' movement. Moreover, there are certain timings that should be enhanced as crucial for action initiation. For example, it should be noted to goalkeepers that it is irrelevant to base their decision on any movement of penalty takers produced until 0.5 s before ball contact (i.e., until a moment close to penalty taker's non-dominant foot placement at the ground), since none of those movements are associated with the direction of the ball. Hence, both in experimental sets or training sessions, task constraints should be manipulated in order to promote the use of the referred relevant information sources.

Despite the relevance of specific information sources in the penalty kick, it was shown on Chapter 3 that performers can achieve the same goals by means of different movement patterns. Thus, it is reasonable to suggest that penalty kick training tasks should promote the co-adaptation between players with opposite goals, appealing to the application of unpredictable movement solutions, in order to endorse adaptation to novel situations.

Finally, as proposed on Chapter 4, novel methodologies for the analysis of goal-directed behaviour should be conceived. The correlation and regression methods applied to penalty takers' movements should be extended to a simultaneous analysis of both players. For example, if an analysis could synchronize the correlations from penalty takers' kinematics and the information sources that goalkeepers are actually relying on, then it would be possible to check the discrepancies on information sources use. From here, coaches can evolve to experimental tasks and training exercises that aim to reduce (for goalkeeper's training) or maintain (for penalty taker's training) those discrepancies.

## 6.6 Future research

Throughout this research program some questions of interest appeared that could be explored on penalty kick future investigation. The ability of players to maintain their efficacy levels despite the imposed constraints (i.e., degeneracy) is a very interesting topic in order to study the processes of adaptability and learning under different environmental and task demands. Relatedly, supposed advantages of using deceptive strategies were not confirmed by our studies. Deceptive action showed no superior efficacy on outcome or on masking genuine actions. Further research could explore in what extent could penalty takers benefit from specific training programs on deceptive and non-deceptive action to improve their deceptive skills and efficacy.

Future research in the penalty kick should adopt a more embracing approach (i.e. based on biomechanical measurements) to the phenomena as a crucial condition to incorporate the spectrum of constraints influencing the behaviour of both players. Moreover, future research should address the individual characteristics of that relevant information. The exploratory analysis performed with each goalkeeper on Chapter 4, revealed that goalkeepers act at different timings. This may indicate that players base their actions on different informational variables, which is consistent with investigation on other tasks (Jacobs & Michaels, 2001; Withagen & van Wermeskerken, 2009).

Questions were also raised concerning the sources of information that predict ball direction and the sources of information that are actually used by goalkeepers in their action. This distinction is important when generalizations from research to training and competition are intended, since areas towards which goalkeepers look at (e.g., Savelsbergh et al., 2002; Savelsbergh et al.,

2005) could not be the most informative with respect to penalty taker's actions. This discrepancy between the areas used by players to guide their actions and the areas where relevant information actually is, constitutes a stimulating research field for future investigation. For example, the application of technology (e.g., eye-tracking systems) associated to task manipulations (e.g., enhancing/hiding body areas) could help investigators to determine the above-mentioned discrepancies. Hence, applications to training can be made, in order to redirect players' attention to more useful information sources.

Finally, future research might study if the information that predicts ball direction is also found across different experimental scenarios (i.e., not only on the field, but also through video observation). Although Dicks and colleagues' (2010a,b) contributed in this matter, it is still possible to include participants without any practice on association football. This might allow to observe if such information sources represent invariants when it comes to predict the intentions of performers.

## 6.7 References

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