

Review

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Goalkeeping in the soccer penalty kick

It is time we take affordance-based control seriously!

Introduction

Saving a penalty kick is an interceptive action. And as Peper, Bootsma, Mestre, and Bakker (1994) eloquently articulated, successfully performing an interceptive action is about ‘getting to the right place at the right time’. Yet, scientists concerned with goalkeeping expertise in penalty kicks have focused primarily on getting to the right side of the goal only.¹ Little or no consideration has been given to how goalkeepers arrive in time to stop the ball. That is, attempts to understand how goalkeepers time the onset of their dive have been conspicuously absent, despite accurate timing being as critical to goalkeepers’ success as choosing the correct side. Arguably, there are plausible methodological and theoretical motives for this disregard of timing. We think it reflects an underlying premise among scientists—but perhaps also in soccer players and coaches—that goalkeeping expertise in the penalty kick is basically a perceptual skill. Our argument in this review is that with this notion the understanding of how expert goalkeepers act (or should act) to save

the ball necessarily remains incomplete. Using affordance-based control as the background theory (Fajen, 2005, 2007), we propose a model that aims to capture that stopping a penalty kick not only requires goalkeepers to get at the right place but also requires them to get there at the right time. Significantly, the model also aims to account for the goalkeepers’ action capabilities. We present directions for testing and developing the model. To set the stage, however, we first review the leading methodological and theoretical approach to goalkeeping in penalty kicking.

The leading approach: saving penalty kicks is a perceptual skill

The goalkeeper’s difficulty in the penalty kick originates from the extreme time constraints of the situation. After the ball is kicked, it takes as little as 500 milliseconds for the ball to reach the goal (Franks & Harvey, 1997; Kuhn, 1988). The goalkeeper needs at least 600 milliseconds to dive to a side and perhaps up to 1000 milliseconds to cover the top corner (Dicks, Davids, & Button, 2010a;

Franks & Harvey, 1997; Tsai, 2005).² Typically, therefore, the time the goalkeeper requires is less than the time available. The implication is that the goalkeeper is often unable to use information from ball-flight to decide to which side to dive, even though this information is most adaptive (i. e., it specifies the ball’s trajectory). Instead, the goalkeeper is thought to depend on information that is available earlier; in particular, information generated as the penalty taker’s actions unfold during the run-up and the kick. However, this early information is less adaptive, and the longer before ball-contact, the more loosely it is coupled to the resulting ball trajectory (Franks & Harvey, 1997; Diaz, Fajen, & Phillips, 2012; Lopes, Jacobs, Travieso, & Araújo, 2014). This presents goalkeepers with conflicting requirements (Navia, Dicks, van der Kamp, & Ruiz, 2017). They may wait long to exploit the specifying information from ball-flight. This ensures an accurate choice of side; however, waiting long can compromise temporal accuracy. Conversely, goalkeepers may safeguard accurate timing and move early, but such

¹ In fact, this is not an idiosyncrasy of soccer penalty kick research, but tends to characterize research of interceptive actions in sport (often referred to as anticipation) more generally (e.g., for recent reviews, see Loffing & Cañal-Bruland, 2017; Morris-Binelli & Muller, 2017).

² These times are estimates derived from experimental studies. Recent measures of ball-flight times and goalkeeper movement times from professional football are not available (cf. Franks & Harvey, 1997; Kuhn, 1988). Note also that the estimates are averages; large variations are reported in ball-flight times or goalkeeper movement times.

moves will be predicated on information that is less adaptive and potentially misleading (i.e., information from the penalty taker's actions is not fully reliable in specifying the ball's trajectory).

In order to examine how goalkeepers adapt to the extreme time constraints, experimental studies have tended to examine goalkeeping expertise in penalty kicking using video technology (e.g., Causer, Smeeton, & Williams, 2017; Diaz et al., 2012; Franks & Harvey, 1997; Loffing & Hagemann, 2015; Neumaier, te Poel, & Standtke, 1987; Savelsbergh, Williams, Ward, & van der Kamp, 2002; Savelsbergh, van der Kamp, Williams, & Ward, 2005; Williams & Burwitz, 1993). During video tasks, goalkeepers are required to respond to footage of players taking a penalty kick. They verbalize the predicted direction of the kick or make simplified (manual) movements to simulate trying to save the kick. Researchers have adopted video tasks, possibly because it increases experimental control of the penalty kick situation. Specifically, by editing the video footage experimenters can precisely determine the information available to the goalkeeper. The video tasks also facilitate the concurrent measurement of gaze. The methodology appears to be in line with theoretical approaches that presume that perception is underpinned by representational structures, which support the encoding of information independent of action (e.g., Ericsson & Kintsch, 1995; Fodor & Pylyshyn, 1981; Williams & Ericsson, 2005). In this view, expertise in perception can, or is perhaps best, examined in isolation from action—as in video tasks. Accordingly, goalkeeping in penalty kicking is a perceptual-cognitive skill that involves the sophisticated processing of information (or cues) from the penalty taker's action by task-specific knowledge structures to predict the oncoming ball trajectory.

Indeed, this body of work suggests that expertise is associated with the information that a goalkeeper processes. The skilled penalty stopper would process or encode information (often called cues) that allows for a more accurate prediction of the ball trajectory than the information used by less proficient penalty

stoppers. Hence, research has tried to delineate the skill-related differences in information use. However, the evidence regarding information use is equivocal; information from the angle of the run-up, the hips, the nonkicking and kicking foot/leg have all been claimed to explicate the advantage of the skilled penalty stopper. This state of affairs has led some to argue that the information may be distributed across different body parts, and that more sophisticated methods of manipulation of video footage are required to delineate the information that skilled penalty stoppers use (see e.g., Causer et al., 2017; Diaz et al., 2012). In contrast, we argue that the incongruent findings highlight the shortcomings of the use of video tasks for examining goalkeeping.

The use of video technology limits the possible responses that participants can make. Most critically, the participants cannot authentically move to physically intercept a ball (van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008). Consequently, the time constraints that characterize the penalty kick situation are not well preserved in studies using video tasks. This is somewhat worrying, given the central aim to appreciate the manner in which high-skilled goalkeepers act under the extreme time constraints of the penalty kick situation. In research using video tasks, the time a goalkeeper has available for responding is not well defined (i.e., it is unclear when the ball passes the goal line) and/or insufficiently constrained (i.e., the verbal or manual response does not have to coincide with the moment the ball passes the goal line). Also, in video tasks, the time a goalkeeper needs to make a response is not representative with respect to the time a goalkeeper needs to intercept a ball on the pitch. Making a verbal response and pressing a button are motorically very different from jumping sideward to cover the goal. Moreover, there will be important skill- and technique-related differences in goalkeepers' agility when diving for the ball, which cannot be considered in video tasks (Dicks et al., 2010a;

Franks & Harvey, 1997; Tsai, 2005).³ Finally, research has almost exclusively focused on identifying the information that goalkeepers exploit to move to the correct side of the goal. We speculate that this one-sided focus on getting to the correct side (and height) is because researchers are (tacitly) aware of the inadequate time constraints within the video tasks. Thus far there has been no single study investigating the information that goalkeepers use—or potentially can use—to time the dive. Indeed, with a few noticeable exceptions (see below), also recent in situ experiments in penalty kicking still focus primarily on information underpinning spatial control (e.g., Dicks, Button, & Davids, 2010b; Lopes et al., 2014a; Piras & Vickers, 2011).

In sum, the use of video tasks has been the dominant methodology for investigating goalkeeping in penalty kicking. This methodology entails that saving a penalty kick is a perceptual skill that can be studied in isolation from a goalkeeper's actions. As a corollary, researchers have disproportionately focused on understanding of the informational basis of spatial control. While the findings are not unambiguous, they have led to straightforward recommendations for practice (van der Kamp & Savelsbergh, 2014; Memmert & Noël, 2017). For example, goalkeepers are advised to dive to the right and left side in the case the opponent's nonkicking foot is oriented to the right and left, respectively. Although simple to adhere to, the recommended rules are context-free: they are impervious to an individual goalkeeper's action capabilities (e.g., agility) and the specifics of a penalty kick (e.g., the power of the kick). They reflect the negligence of time in the dominant video

³ Virtual reality (VR) applications may offer a promising alternative to video tasks. VR allows representative time constraints, provided that the participant can dive to intercept the ball in a space that equals the size of the goalmouth. It needs to be confirmed, however, that diving for a virtual ball does not disrupt normal movement control. For example, there is evidence to suggest that interacting with virtual objects can result in increased engagement of the ventral system in movement control (Rinsma, van der Kamp, Dicks, & Cañal-Bruland, 2017; Whitwell, Ganel, Cavina-Pratesi, Byrne, & Goodale, 2015).

task methodology.⁴ Interestingly, Dreyfus (2002, 2008) associated the use of context-free rules with beginner learners. Dreyfus is a philosopher within the tradition of existential-phenomenology, who argues that skillful action can be described and explained without recourse to internal knowledge structures. He distinguishes five stages that learners normally progress through when acquiring a skill. Initially, context-free rules do promote learning, but to achieve proficiency learners must move away from reliance on these rules, also unconsciously. According to Dreyfus, it is the more subtle and refined perception of what a situation affords that distinguishes an expert from a beginner. This view is reminiscent of what ecological psychologists have described as affordance-based control (e.g., Fajen, 2007). Consequently, goalkeeping expertise in penalty kicking would be more completely, and perhaps more accurately, conceived in terms of affordance-based control, rather than by recourse to rules. It is time we turn to affordance-based control theory.

The affordance-based control theory

Affordance-based control theory asserts that actions are controlled by the perception of affordances (Fajen, 2005, 2007; Fajen, Riley, & Turvey, 2008). Affordances are the possible actions that a situation offers (Gibson, 1979). Actors move in ways that sustain the perception of the affordance they want to achieve. It is crucially important to appreciate the subtle distinction with actions or movements being controlled by information, as ecological psychologists have traditionally argued (e.g., Lee, 1976; Michaels & Oudejans, 1992; Peper et al., 1994; Warren, 1988). Take for example, an outfielder in baseball running to catch a fly ball (Postma, Smith, Pepping, van Andel, & Zaal, 2017; see also Fajen, 2007). According to a widely

⁴ More complicated rules have been advised that direct attention to information distributed across the body of the penalty taker during the run-up (e.g., Ryu, Kim, Abernethy, & Mann, 2013; Savelsbergh, van Gastel, & van Kampen, 2010), but also these ignore timing.

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Goalkeeping in the soccer penalty kick. It is time we take affordance-based control seriously!

Abstract

The goalkeeper's difficulty in the soccer penalty kick originates from the extreme spatiotemporal constraints of the situation. The present review claims that the current understanding is biased toward attributing a goalkeeper's success in saving a penalty kick to perceptual-cognitive skill. To investigate the goalkeeper's skill, researchers have often adopted video tasks. In doing so, they studied perceptual skill in isolation from action. We use affordance-based control theory to propose an alternative understanding and research methodology. We argue that

goalkeepers in the penalty kick situation should regulate their actions in ways that sustain the perception of stoppability. To capture this, we outline the building blocks for a required lateral velocity model, in which the goalkeepers' required actions are scaled to their maximum capabilities. In doing so, we provide new directions for research.

Keywords

Goalkeeping · Penalty kick · Anticipation · Timing · Affordance · Required velocity

Torhüten beim Strafstoß im Fußball. Nehmen wir die affordanzbasierte Kontrolle endlich ernst!

Zusammenfassung

Die Schwierigkeiten für den Fußballtorhüter beim Strafstoß beruhen auf den extremen räumlich-zeitlichen Einschränkungen der Situation. In der vorliegenden Übersicht postulieren wir eine Verzerrung der aktuellen Deutung dahingehend, dass der Erfolg eines Torhüters beim Parieren eines Strafstoßes der perzeptorisch-kognitiven Fertigkeit zugeschrieben wird. Zur Untersuchung der Fertigkeit des Torhüters werden häufig Videoaufgaben genutzt. Auf diese Weise wird die perzeptorische Fertigkeit isoliert von der Handlung betrachtet. Ausgehend von der Theorie der affordanzbasierten Kontrolle schlagen wir eine alternative

Deutung und Forschungsmethodik vor. Wir argumentieren, dass Torhüter in der Strafstoßsituation ihre Handlungen so steuern sollten, dass die Wahrnehmung der Haltbarkeit aufrechterhalten bleibt. Zur Erfassung umreißen wir die Bausteine eines Modells der erforderlichen lateralen Geschwindigkeit, in dem die erforderlichen Handlungen der Torhüter auf ihr maximales Leistungsvermögen skaliert sind. Damit werden neue Forschungsimpulse gesetzt.

Schlüsselwörter

Torhüten · Strafstoß · Antizipation · Timing · Affordanz · Erforderliche Geschwindigkeit

accepted model, the outfielder's running is guided by the optical acceleration of the ball (Chapman, 1968; Michaels & Oudejans, 1992). That is, the outfielder must move so that a particular pattern of information is produced, in this case assuring that the optical acceleration is canceled out. Specifically, if current optical acceleration exceeds zero, the outfielder must run backward until it equals zero, and if maintained, the fielder will arrive at the right place at the right time to catch the ball. If, however, optical acceleration is below zero then the outfielder must run forward, and so on. This model thus explains how information is used or generated to control running (i.e., in-

formation-based control). Importantly, however, the model is not constrained by the action capabilities of the outfielder, and consequently, fails to specify whether the ball affords catching or not (Fajen, 2005, 2007). The ball is only perceived as catchable for the fielder if she or he can run fast enough to cover the distance to the interception location in time. If the required running velocity exceeds the running speed that the outfielder can achieve (or maintain), then the fly ball is no longer perceived as catchable—in that case the outfielder is perhaps better off preparing to get the ball after a bounce (Postma et al., 2017). Consequently, to be successful, the outfielder must run in

order to ensure that the required running velocity is kept within the limits of her or his running capabilities, that is, within the action boundaries. In affordance-based control, the boundaries of action “impose a critical constraint on successful performance to which actors must be sensitive” (Fajen, 2007, p. 391). Hence, the outfielder only needs to make adjustments in current running if the required velocity comes close to the boundary of the maximal running speed that can be maintained; otherwise, a catch becomes impossible.

Affordance-based control entails that a situation is perceived in action-relevant properties. For the outfielder, this would be in units of maximum running speed, rather than in ball speed or landing location and time. This implies that information must be scaled to action capabilities (for an overview, see van Andel, Cole, & Pepping, 2017). The perception of the affordance is not independent of the action capabilities. The exact scaling differs depending on the individual (hence, the ubiquitous intra- and interindividual differences) and the spatiotemporal constraints. A strained hamstring, fatigue or a heavy rainfall, which turns the playing field muddy, affect the running speed that can be achieved, and hence, will make recalibration necessary for the outfielder. Accurate recalibration, however, requires practice and experience (see Fajen, 2005, 2007; van der Kamp & Renshaw, 2015 on how actors can learn to recalibrate). In fact, this sensitivity to situational constraints and one’s action boundaries highlights the actor’s adaptability as a prime characteristic of expertise (see also Kimmel & Rogler, 2018).

Affordance-based control in goalkeeping in the penalty kick: a proposal

Taking affordance-based control seriously implicates that we work towards developing a model for the guidance of the goalkeeper’s interceptive action. Here, we aim to outline the first building blocks for such a model. These building blocks capture the (minimum) constraints that need to be satisfied to successfully save a penalty kick. In this

respect, the model is meant to be more complete and accurate than previous work on goalkeeping in the penalty kick situation. The model will also help to identify the information a goalkeeper would need to intercept a ball. As it turns out, only a small part of this information has been delineated, and most likely, some of the required information is most likely not available to the goalkeeper—confirming that the penalty kick is indeed a penalty. Finally, we would need to assess what information goalkeepers are actually using. Only then would we be able to clarify skill differences in penalty goalkeeping. Due to a lack of empirical studies, however, we have to limit ourselves to providing directions for future research.

Time to introduce the model. By approximation, the goalkeeper moves the body and/or arms in the lateral plane either to the left or to the right side. Such skilled action is in keeping with the required velocity model for lateral interceptions with the hand (Peper et al., 1994; see also Jacobs & Michaels, 2006); however, some task-specific modifications are necessary. The relevant control variable would be the goalkeeper’s lateral velocity (V_{GK}).⁵ Consequently, the goalkeeper must perceive the required lateral velocity, which is defined as the difference between the position the ball crosses the goal line (X_B) and the goalkeeper’s posi-

tion on the goal line (X_{GK}),⁶ divided by the time available before the ball reaches the goal line. The time available is the sum of the time remaining before the kicker strikes the ball (TTC_{PT}) and the ball flight time (TTC_B). Importantly, affordance-based control requires that the regulated variable be scaled to the action boundaries. Hence, we use V_{GK}^* to express that the regulated lateral velocity is in units of maximum lateral velocity. The resulting model can be described by a differential equation:

$$V_{GK}^* = c \left(\frac{X_B - X_{GK}}{TTC_B + TTC_{PT}} \right) \quad (1)$$

where c is the scaling or calibration variable for getting the required lateral velocity ($\frac{X_B - X_{GK}}{TTC_B + TTC_{PT}}$) and the regulated lateral velocity (V_{GK}^*) in the same units. Thus, with the unfolding of the penalty kick, the required lateral velocity increases. As long as the required lateral velocity is below the maximum lateral velocity that the goalkeeper can (still) achieve (i.e., $V_{GK}^* < 1.0$), the kick can be stopped. The goalkeeper perceives the ball as stoppable. However, if the required velocity exceeds maximum velocity (i.e., $V_{GK}^* > 1.0$), then it is impossible to stop the ball. To stop the ball the goalkeeper must start diving before the required velocity exceeds the maximum achievable velocity. In other words, the goalkeeper must move such as to sustain the perception that the ball is stoppable. The goalkeeper must therefore be sensitive to their maximum lateral velocity (at takeoff, see footnote 5).

Accordingly, an important empirical goal is to examine whether goalkeepers that have high success rates in saving penalty kicks are indeed calibrated to their maximum lateral velocity. The studies using video technology are necessarily mute to this issue. By contrast, Dicks et al. (2010a) investigated goalkeepers who actually jumped to try and save penalty kicks. They found large individual differences in when goalkeepers

⁵ If we presume that the goalkeeper makes a sideward jump, then the final instant for regulating velocity would be at takeoff. Adjustment cannot be made while in the air—that is, except for the final hand movements during the jump. In addition, with respect to the height of interception the direction of velocity is also relevant. We do not take this into account here. Nevertheless, within a more refined model, the control variable is likely more precisely defined as the velocity and its direction at takeoff (i.e., as a vector). Finally, Warren, Young, and Lee (1986) argued that in running over irregular terrain, step time (and thus length) is regulated by varying the vertical impulse I_v applied to the ground. We did not consider in detail whether or not this is a (more) appropriate control variable for the goalkeeper diving to intercept the ball.

⁶ X_B and X_{GK} are taken relative to the midpoint of the goal line, which is defined as 0. Consequently, the right and left goal sides are indicated by positive and negative X-values, respectively. Similarly, velocity to right and left goal sides are indicated by positive and negative V-values, respectively.

started their dive to the side (i.e., between 50 and 350 milliseconds before ball-contact). Instead of velocity, the authors chose to describe the situation in terms of time. Accordingly, when they scaled time of movement onset to the minimum time the goalkeeper needed to cover the goal (which, in all likelihood, highly correlates with the maximum velocity the goalkeeper can achieve), the interindividual differences in timing were significantly reduced. Notably, the goalkeepers tended to start after the required time exceeded the available time (i.e., they waited too long, that is, until after required velocity had exceeded maximum velocity). Still, the two goalkeepers who made the most saves were closest to their action boundary, although not all proficient goalkeepers acted close to their action boundary (see also Navia et al., 2017). This suggests that these goalkeepers were not optimally calibrated. Alternatively, one might speculate that the goalkeepers did not try to cover the entire goal area or were stepping forward (i.e., both strategies would reduce $X_B - X_{GK}$), and were calibrated accordingly. Anyhow, the observations provide the first (indirect) evidence that (more successful) goalkeepers are indeed sensitive to their action boundaries—presumably in terms of maximum attainable velocity, but such suggestion needs further verification. Also to further evidence that goalkeepers scale required velocity in units of maximum velocity, researchers can test the effects of manipulating the goalkeeper's action capabilities, for instance, by having them attempt to save kicks on a sandy pitch or by attaching weights to their ankles (Dicks & van der Kamp, 2016).

Affordance-based control requires that the right-hand side of the equation is written in optic (or other informational) variables. This demands that we delineate the optic variables that together specify required velocity. The research agenda would then be to demonstrate that actors are indeed attuned to these informational variables (e.g., Jacobs & Michaels, 2006). Yet, current understanding is too fragmented to be able to identify all variables, let alone show that goalkeepers are using them. We

especially lack hints toward the variables representing the time available in the denominator. By contrast, for the location variables in the numerator, and in particular X_B , previous work is valuable.⁷ For the location the ball crosses the goal line (X_B), biomechanical analyses indicate that information generated by the penalty taker's movements (i.e., angle of approach, hip, nonkicking and kicking foot/leg, respectively)⁸ increases in reliability the closer the player gets to ball-contact (Diaz et al., 2012; Lopes et al. 2014a). After ball-contact ball-flight information is specific to X_B (Jacobs & Michaels, 2006). Still, the required lateral velocity model outlined here allows us to better understand intra- and interindividual variability among goalkeepers with respect to the variables they are (or should be) attuned to. That is, to arrive in time, goalkeepers would have to start early and thus be forced to use less reliable and potentially misleading information when they face relatively powerful kicks and when they are less agile or fatigued. Thus far, these hypotheses have not been directly tested. Nonetheless, by using in situ occlusion in ways that block progressively longer parts of the penalty taker's run-up from vision, Dicks, Button, and Davids (2010c) showed that earlier initiation of the movement time made goalkeepers more susceptible to deception. Finally, goalkeepers need information about their position on the goal line, X_{GK} , especially when they are moving sideways before the kick and for making final hand adjustments in flight. This information has not been addressed, but is likely to include kinesthetic sources (see Jacobs & Michaels, 2006).

⁷ Notice, we are referring here to the *identification* of optic variables that inform about location or side. This must not be confused with showing that goalkeepers actually *use* this information. As we have argued in Sect. 2, we are unconvinced that observations from the video task paradigm can give conclusive answers about the goalkeepers' use of information.

⁸ To be sure, this information from the penalty taker's movements is shown to correlate with side. It remains to be seen how accurate they are regarding the exact location at which the ball will cross the goal line.

A new challenge set by the required lateral velocity model is to determine the informational variables about the time available until the ball passes the goal line, that is, $TTC_B + TTC_{PT}$. After ball-contact, the situation is relatively simple. TTC_{PT} is zero, and the resulting time available equals TTC_B . TTC_B is fully specified by ball-flight information from the optical angle subtended by the ball at the goalkeeper's point of observation and the azimuthal angle, which relates to the direction of ball flight relative to the goalkeeper's line of sight (for details, see Jacobs & Michaels, 2006, Fig. 2). In all likelihood, however, the average goalkeeper must move before the penalty taker strikes the ball (Fariña, Fábria, Tambusso, & Alonso, 2013; Hughes & Wells, 2002). This implies that information about $TTC_B + TTC_{PK}$ must become available from the penalty taker's actions that unfold in the run-up. Information about TTC_{PT} , the time remaining before the penalty taker contacts the ball might be related to the optical angle subtended by the penalty taker at the goalkeeper's point of observation, but only if the run-up is fluent (i.e., constant speed and/or acceleration) (Lee, 1976). In addition, the penalty taker's movements may provide information about TTC_B . The length, speed, and fluency of the run-up (Kuhn, 1988; Noël, Furley, van der Kamp, Dicks, & Memmert, 2015; cf. Hughes & Wells, 2002), and speed of the shank and kicking foot (Barberi, Gobbi, Santiago, & Cunha, 2010; Nunome, Ikegami, Kozaikai, Apriantono, & Sano, 2006) are candidate sources. For instance, Barberi et al. (2010) found a moderately strong correlation between velocity of the kicking foot and ball speed. Similar to information about X_B , this information is unlikely to become fully specific for TTC_B , although it might increase in reliability the closer the player gets to ball-contact.

Intriguingly, there is some evidence to suggest that goalkeepers are indeed attuned to information about $TTC_B + TTC_{PT}$. Navia et al. (2017) manipulated ball-flight duration by having penalty takers take kicks from different distances. They found that goalkeepers adapted to the different temporal constraints by directing gaze more often

to the ball and waiting longer in the case of prolonged ball-flight durations. Clearly, we need biomechanical analyses to determine how movements from the penalty takers correlate with ball-flight times (cf. Diaz et al., 2012; Lopes et al., 2014a). Manipulation of run-up speed and fluency, and kicker distance can further facilitate this effort.

Future challenges

Affordance-based control holds that goalkeepers in the penalty kick situation must act in ways that sustain the perception of the ball being stoppable. Our model implies that goalkeepers keep the required lateral velocity within their action boundaries—lower than the maximum lateral velocity they can attain. Once this maximum lateral velocity is exceeded, the goalkeeper will be unable to get to the right place at the right time. The situation does not afford stopping the ball anymore. It is significant to recognize that the goalkeepers' affordance perception in the penalty kick situation emerges from the interaction with the penalty taker. The two players have diametrically opposing goals, resulting in very complex affordance dynamics (Kimmel & Rogler, 2018). The penalty taker will act in ways that dissolves the goalkeepers' perception of the ball being stoppable (i.e., they will try to 'increase' the required velocity beyond a goalkeeper's maximum velocity). The shift from the ball being perceived as stoppable to unstoppable can be very sudden, particularly when penalty takers try to hide their true intention or deceive the goalkeeper. The implication is that goalkeepers should act critically close to their maximum action boundaries: goalkeepers who act early allow the penalty taker to thwart the goalkeepers' efforts by kicking to the other side of the goal. The perception then suddenly flips in the ball being unstoppable. Goalkeepers thus act in a situation of the barely possible. Paraphrasing Kimmel and Rogler (2018), who used affordance-based control to describe analogous antagonistic encounters in combat sports, goalkeepers 'are quickly lost when their sustaining actions are a bit off or the opponent's

counteractions increase a tad'. In this respect, Kimmel and Rogler (2018) refer to brinkmanship. The expert athlete pursues a difficult strategy to the limits of what is possible. For the skilled goalkeeper, this may also include acting to subtly entice the penalty taker into kicking in a certain direction (e.g., Masters, van der Kamp, & Jackson, 2007; van der Kamp & Masters, 2008). These are very complex interactive dynamics indeed, but—importantly—affordance-based control gets them into view. In doing so, affordance-based control also directs empirical efforts towards the actual *dueling* in the penalty box, that is, the evolving interactions between goalkeeper and penalty taker (see Lopes, Araújo, & Davids, 2014b; Lopes et al., 2014a).

As emphasized above, with the current model we aim to capture the constraints that need to be satisfied to successfully save a penalty kick. The next step is to more fully delineate the information that is available to goalkeepers, and—critically—to assess what information they are actually using. It is our conjecture that the latter can only be accomplished by investigating the evolving interactions between goalkeeper and penalty taker. VR and surely video tasks fall short in achieving this. Such empirical investigations must uncover what information goalkeepers are attuned to and whether their actions are properly scaled to the maximum action capabilities. Most likely, the more successful penalty stoppers will not only be better calibrated to their action capabilities, but will also distinguish themselves from less proficient goalkeepers by using more adaptive and less misleading information, i.e., information that is more strongly correlated to the properties that constitute the required lateral velocity. Conversely, goalkeepers who attend to less reliable or misleading information and/or inappropriately calibrated will be less likely to stop a penalty kick.

The proof of the pudding is in the eating. Since its introduction in 1891, the rules of the penalty kick have evolved so that the time constraints provide a clear advantage for the penalty taker (van der Kamp & Savelsbergh, 2014).

As a consequence, it is improbable that the information available in a typical penalty kick situation fully specifies the goalkeeper's required lateral velocity. That is why stopping a penalty is so difficult. Hence, to evaluate whether affordance-based control enhances understanding of goalkeeping expertise in penalty kicking and results in more comprehensive recommendations awaits further investigations. Not surprisingly, we see good prospects, if only because the recommendations will be grounded in a goalkeeper's action capabilities. This perspective will support individually tailored interventions, which are particularly commonplace with elite-level populations (see Pocock, Dicks, Thelwell, Chapman, & Barker, 2017). We encourage researchers and students to join our efforts to test and develop this affordance-based control model for penalty goalkeeping, and more general, toward similar models for interceptive actions in other sports.

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Compliance with ethical guidelines

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This article does not contain any studies with human participants or animals performed by any of the authors.

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