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Individual differences in performance and learning of visual anticipation in expert field hockey goalkeepers

Khaya Morris-Binelli [a,*], Sean Müller [a], Fleur E.C.A. van Rens [a], Allen G. Harbaugh [b], Simon M. Rosalie [c]

[a] Discipline of Exercise Science, Murdoch University, Perth, Australia
[b] Cook-Cole College of Arts and Sciences, Longwood University, Farmville, Virginia, USA
[c] School of Physiotherapy and Exercise Science, Curtin University, Perth, Australia

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ABSTRACT

The study of anticipation in truly expert performers can provide insight into how they cope with extreme time constraints. The purpose of this dual-experiment paper was to investigate individual differences; in anticipation of the penalty corner drag-flick, its trainability, and transfer of improvement to field settings. Australian international and national male field-hockey goalkeepers participated. In experiment 1, international and national goalkeepers ($n = 11$) completed a penalty corner drag-flick temporal occlusion task that presented; defensive runner positioning at the penalty spot, drag-flicker kinematics, and ball flight. Results indicated seven goalkeepers integrated runner contextual and drag-flicker kinematic information to anticipate above chance. The cause of individual differences was independent pick-up of run and kinematic cues that presented greater opportunity to integrate sources for anticipation. In experiment 2, a sub-sample of goalkeepers participated and received temporal occlusion training or no training. Results indicated individualized improvement in anticipation across video, field, and competition assessments for those that received the intervention, but not controls. Improvements on video test were retained for six months. An individual differences approach can identify deficiencies in anticipation, which can be improved through perceptual training that transfers to motor responses. This contributes to theoretical and practical knowledge to develop anticipation skill.

The field of expertise in cognitive and motor domains has consistently investigated truly expert performers, who have reached the highest level of competition, in order to understand perceptual and motor performance (e.g., Bootsma & van Wieringen, 1990; Chase & Simon, 1973; Land & McLeod, 2000). Truly expert performers are few in numbers and form small populations, because as skill level increases, the total number of performers at the highest skill level decreases (Müller, Brenton, & Rosalie, 2015; Walsh, 2014). For example, in field hockey, the Australian international men's and women's teams include at times three to four goalkeepers within each squad. Studies that have investigated performance of truly expert performers have made unique advancements to knowledge of the underlying mechanisms of expertise and shaped future research directions (Abernethy, Gill, Parks, & Packer, 2001; Land & McLeod, 2000). Furthermore, these studies provide information that can be used to tailor training programs for those individuals, as well as emerging-expert athletes and lesser skilled performers (Bilalić, McLeod, & Gobet, 2008).

Visual anticipation is well established as a critical expertise skill for superior performance in high time-constrained sports skills such as field hockey goalkeeping (Abreu, Candidi, & Aglioti, 2017). In the literature, visual anticipation is defined as the capability of the performer to pick-up *advance* visual cues from opponent contextual (e.g., player positioning) and kinematic (movement pattern) information, as well as object flight information to predict what will happen and guide motor responses (Müller & Abernethy, 2012). Anticipation is necessary by the performer because in ballistic sports skills such as field hockey goalkeeping at the international level, the ball can take as little as 350 ms from the drag-flicker's stick until it reaches the goalkeeper (Baker, Farrow, Elliott, & Anderson, 2009; Williams & Jackson, 2019). The drag-flicker is a key attacking player who positions themselves with other attacking players at the top of the shooting circle during a set play penalty corner. Another attacking player known as the injector, pushes the ball from the attacking goal baseline to a trapper positioned at the top of the shooting circle who stops the ball with their stick for the

* Corresponding author. Discipline of Exercise Science, Murdoch University, 90 South Street, Murdoch, Perth, 6150, Australia.
E-mail address: K.Morris-Binelli@murdoch.edu.au (K. Morris-Binelli).

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drag-flicker. The drag-flicker's role is to then sling the ball into a target location of the goal at high-speed in order to score. Given that the drag-flicker can deliver the ball to between four to six target goal locations, this can result in a four-choice reaction time of approximately 400 ms for the goalkeeper (Müller & Abernethy, 2012; Rosalie et al., 2017). Therefore, the performer needs to pick-up advance visual cues to limit the reaction time delay and respond in a timely manner to achieve the skill goal.

In their two-stage model of visual anticipation, Morris-Binelli and Müller (2017) outline how visual information is used to guide action. In stage one, the performer pick-ups contextual and kinematic (advance) information to anticipate and guide positioning of the body. For example, in field hockey goalkeeping, contextual information refers to pick-up of defensive runner location relative to the penalty spot during the penalty corner. Kinematic information refers to the drag-flicker movement pattern that is used to direct the ball to different goal locations. In stage two of the model, the performer pick-ups ball flight information to anticipate and fine-tune body position for interception. In field hockey goalkeeping, ball flight information can be used to fine-tune positioning of the hand or foot to save the goal. A large body of work has confirmed pick-up of kinematic (e.g., Abernethy & Russell, 1987b; Panchuk & Vickers, 2009) and object flight (e.g., Panchuk & Vickers, 2009) information for anticipation. Less is known about whether performers can integrate contextual and kinematic information to anticipate, individual differences in this capability, as well as how training information pick-up benefits individual performers (Morris-Binelli & Müller, 2017).

The video-based temporal occlusion paradigm has been predominantly used to investigate how *groups* of higher and lower skilled performers use contextual with kinematic information to anticipate (Morris-Binelli & Müller, 2017). Briefly, the purpose of temporal occlusion is to control the duration of visual information presented to the participant (Abernethy & Russell, 1987a). Temporal occlusion involves footage of an opponent executing skills such as different ball types in cricket, which are edited to place a black video frame at key events such as at ball release or during ball flight (Runswick, Roca, Williams, McRobert, & North, 2018). Thereafter, a randomized sequence of temporal occluded skill types is presented to participants on a projector screen, and after occlusion, they can be required to anticipate object location using a verbal, pencil and paper, or simulated motor response (Fadde, 2016; Williams & Jackson, 2019).

Studies that have used video temporal occlusion have reported that *groups* of higher skilled players are superior to *groups* of lesser skilled players in the pick-up of contextual cues to anticipate, such as field-placings in cricket batting (Runswick et al., 2018), server preferences in tennis return of serve (Farrow & Reid, 2012), pitch count in baseball batting (Paull & Glencross, 1997), and court positioning in tennis return of serve (Loffing & Hagemann, 2014). Importantly, studies have reported that even highly skilled players have difficulty integrating contextual and kinematic information to anticipate (Runswick, Roca, Williams, McRobert, & North, 2019). This has implications for theory and practice as follows. First, impaired selective attention to contextual and kinematic information can delay stage one response in the anticipation model. Second, an opponent could exploit a performer's weakness to integrate these information sources by forcing the performer to respond with their less proficient skill set. For example, in the penalty corner, this could involve a scenario where the drag-flicker targets the left goal locations because the goalkeeper is not aware that the defensive runner positioning increases goal scoring options (Morris-Binelli, van Rens, Müller, & Rosalie, 2020). Understanding individual differences in the capability to integrate information to anticipate can provide fine-grained detail to help improve deficiencies.

There is scant evidence on the use of video-based temporal occlusion to investigate individual differences in perceptual anticipation, its trainability, and transfer in sport (Morris-Binelli & Müller, 2017). Like performance studies discussed above, training studies that have used video-based temporal occlusion, have mainly investigated *group*-based improvement to anticipation. For example, in training, temporal occlusion is applied at key events (e.g., ball release or racquet-ball contact), and after the participant has made a prediction, the same trial is displayed without occlusion to provide feedback for learning. Studies using this approach have reported improvement on video (Abernethy, Schorer, Jackson, & Hagemann, 2012) and field (Fadde, 2016; Smeeton, Hodges, Williams, & Ward, 2005; Williams, Ward, Knowles, & Smeeton, 2002) tests. Two studies have employed video temporal occlusion training to investigate individual improvements in anticipation (Müller, Gurisik, Hecimovich, Harbaugh, & Vallence, 2017; Scott, Scott, & Howe, 1998). Both studies were conducted over a very short time frame of between one and three sessions and focused upon improving pick-up of kinematic information. Nonetheless, improvements to in-situ performance were found, but the magnitude of improvement varied across individual participants. There is scope to build upon this literature to determine individual improvements to pick-up of contextual and kinematic information through video temporal occlusion training.

Field hockey goalkeeping was used as the exemplar high-speed striking sport skill to investigate individual differences in anticipation. Saving the penalty corner drag-flick on goal requires anticipation because there is complex contextual information due to multiple positioning of defensive and offensive players. Moreover, through subtle manipulation of their kinematics, international drag-flickers can strike six goal locations if the defensive team's main runner does not make it directly to the penalty spot to block the shot on goal. This can expose the goalkeeper if they do not read whether the goal is "open" or "closed" (contextual information) and the shot locations (kinematic information; Morris-Binelli et al., 2020). Two experiments are reported involving highly specialized expert (international) and emerging-expert (national) goalkeepers in Australia. The overall purpose of this paper was twofold. First, experiment 1 investigated individual differences in goalkeepers' capabilities to anticipate the drag-flick on goal. Second, experiment 2, built upon experiment 1 to investigate whether anticipation could be improved through video temporal occlusion training, and whether improvement transferred to in-situ settings. Respective performance and learning components of the experiments were based upon relative accessibility to goalkeepers.

1. Experiment 1

Existing knowledge of anticipation in sport is based upon group-designs where experts or skilled performers are compared to lesser skilled performers or novices. This approach has been useful to understand how anticipation is differentiated across extremes of the skill continuum. This can, however, mask individual capabilities or deficiencies, which prevents conclusions about how individual athletes anticipate successfully or unsuccessfully. Therefore, the specific purpose of experiment 1 was to investigate individual differences in the capability of goalkeepers to pick-up, and integrate, contextual (goal open or closed) and kinematic (goal location) advance information to anticipate the drag-flick. Through this, it was possible to delineate the perceptual causes of individual differences to anticipation. It was hypothesized that there would be individual differences in the capability to integrate contextual and kinematic information to anticipate penalty corner drag-flick shots on goal.

1.1. Method

1.1.1. Participants

A total of 11 expert and emerging-expert male field hockey goalkeepers ($M_{age} = 25$, $SD = 4.38$) were recruited to partake in this study. The expert goalkeepers ($n = 4$) played at international level for the Australian national field hockey team. These goalkeepers had played an average of 77 ($SD = 65.04$) international matches, and had been playing competitively as specialist goalkeepers for an average of 17 years ($SD =$

5.60). The emerging-expert goalkeepers ($n = 7$) played at national level in competitions such as Hockey One (formerly Australian Hockey League) for state (provincial) high-performance teams across Australia. They had been playing competitively as specialist goalkeepers for an average of 11 years ($SD = 2.64$). The emerging-expert goalkeepers were identified by national team coaches to have the capability to play for Australia. Collectively, these goalkeepers comprised the entire population of expert and emerging-expert male goalkeepers in Australia. Goalkeepers are specialist position players in a field hockey team, so with an increase in skill level there is a smaller pool of truly expert position players (Müller, Brenton, & Rosalie, 2015; Swann, Moran, & Piggott, 2015). As this study investigated individual differences in the capability to anticipate, each dependent variable was powered and analyzed based upon individual trials for each participant (Müller, Brenton, Dempsey, Harbaugh, & Reid, 2015). Accordingly, a-priori power analyses were conducted to ensure that each dependent variable had enough trials per participant to detect small effects (see statistical analysis section for details). Ethics approval was received from the relevant institution and all participants provided written informed consent.

1.1.2. Instrument Design

A high-speed video camera (GoPro model HERO4) sampling at 120 frames-per-second was used to capture footage of typical penalty corner scenarios. This involved a defensive player running towards a trapper, and a specialist drag-flicker executing penalty corner drag-flicks at goal. Two defensive runners, injectors, trappers, and drag-flickers participated in the filming and were members of the Australian national men's field hockey team. The GoPro was positioned on the goalkeeper's *offset* (one side-step right from the middle of and on the goal line) starting position, at a height that approximately matched the goalkeeper's viewing perspective in a game.

The defending runner was instructed to execute two run types, which are common in an international match: (1) a "tight" run, where the runner's body passes over the penalty spot restricting the drag-flickers capability to shoot at the left side of the goal from the goalkeepers perspective (i.e., goal face closed), and (2) a "loose" run, where the runner's body is to the left of, and misses, the penalty spot, which allows the drag-flicker to shoot at the left side of the goal (i.e., goal face open). Based upon expert coach advice, this defending runner acts as contextual information in a penalty corner (i.e., player positioning), as a tight or loose run can determine the likelihood of the number of goal locations the drag-flicker can direct the ball towards (Morris-Binelli et al., 2020). Each of the two drag-flickers were instructed to deliver two sets of drag-flicks to six goal locations; top-right (1), bottom-right (2), top-middle (3), bottom-middle (4), top-left (5), and bottom-left (6), when the runner executed a loose run. In addition, each drag-flicker was instructed to deliver two sets of drag-flicks to four goal locations; top-right (1), bottom-right (2), top-middle (3), and bottom-middle (4), when the runner executed a tight run. Accordingly, each drag-flicker executed 20 unique drag-flicks on goal. Before each penalty corner, the runner and drag-flicker were informed which run type and goal location was required. During filming, an expert goalkeeping coach viewed each penalty corner and verified whether the defender had executed a tight or loose run. Later, the same coach viewed the footage and confirmed whether the skills were executed to international standard, with the selected footage used in test trials.

The footage was edited using Adobe Premiere Pro CS6 to create a temporal occlusion video test that consisted of 120 test trials. These trials consisted of 3 (temporal occlusion conditions) × 6 (goal locations) × 4 (unique versions; 2 from each drag-flicker) for loose runs + 3 (temporal occlusion conditions) × 4 (goal locations) × 4 (unique versions; 2 from each drag-flicker) for tight runs. Temporal occlusion was applied at selected events to present contextual and kinematic information as follows. First, footage was occluded when the defending runner was in line with the penalty spot (Run). This occlusion was chosen as it occurs at the beginning of the drag-flicker's action and presented contextual information. Second, footage was occluded immediately prior to ball release from the drag-flicker's stick (Stick-Ball). This occlusion displayed the defender's run and drag-flicker's movement pattern, which presented contextual and kinematic information. Third, a no occlusion control condition was included to provide all visual information prior to, at, and after ball release (Ball Flight; see Fig. 1).

Test trials were presented in a single block with the order randomized. Each trial began with a 1 s still frame of the trapper and drag-flicker at the top of the penalty circle to allow the participant time to orient to the task and played afterwards. Trial numbers were presented centrally on the screen before the commencement of the footage. An intertrial interval (ITI) of 5 s occurred between each trial, followed by an audible tone 4 s into the ITI to notify the approach of the next trial.

1.1.3. Procedure

The temporal occlusion test was projected through a Dell Latitude laptop (model E5570) and an Acer high-definition projector (model H1P1117) onto a screen (1.88 m × 1.18 m) in a room. Participants stood 5 m from the screen to create a mathematically calculated viewing angle of the drag-flicker of 8°, as would occur in a match. Masking tape was placed on the floor to demarcate the goal configuration and offset stance position (see Fig. 2). On each trial, as would occur in a match, participants started on the offset goal line position, took one step forward and watched the footage. Immediately after the conclusion of the footage, participants verbalized the run type (i.e., tight or loose) and the balls goal location (i.e., 1 to 6). This response mode was deemed appropriate based upon literature that has reported activation of the motor system in visual-perception tasks (e.g., Aglioti, Cesari, Romani, & Urgesi, 2008). To minimize cognitive fatigue, the test was completed in three blocks of 40 trials, with a few minutes break between each block. Participants completed the test individually with a video camera (GoPro model HERO6 Black) positioned behind to record footage and audible response for later coding (Brenton, Müller, & Mansingh, 2016). To familiarize participants with the task, they were shown an unoccluded trial of each run type and goal location combination, followed by four temporal occlusion trials with feedback. During the test phase, familiarization trials were not included, and participants were not given feedback. Familiarization and test trials took approximately 25 minutes to complete.

1.1.4. Dependent Measures and Statistical Analyses

To address the hypothesis, data analysis selectively focused upon each goalkeeper's prediction of run type (contextual information) and goal location (kinematic information) combined relative to each run type at each of the temporal occlusion conditions. The main focus, however, was the stick-ball temporal occlusion condition that presented both contextual and kinematic information. There were two primary dependent variables; (a) absolute correct prediction accuracy for a loose run and goal location (i.e., goal open = six locations), and (b) absolute correct prediction accuracy for a tight run and goal location (i.e., goal closed = four locations). A secondary dependent variable was analyzed to investigate what underpinned individual integration of information pick-up; that is, absolute correct prediction accuracy of run type and location independently at the stick-ball temporal occlusion condition. Data are plotted as percentages for individual goalkeepers for ease of graphical display.

To investigate the hypothesis, the statistical test focused upon whether anticipation was above chance level because this has been previously reported in the literature to indicate information pick-up (Abernethy & Zawi, 2007; Causer, Smeeton, & Williams, 2017). As the dependent variables were categorical, non-parametric binomial tests were used (Russo, 2004). The purpose of this test was to determine whether each participant predicted above, at, or below the guessing level of 8.3% for loose run and goal location (i.e., possibility of two run types × six goal locations = 12 possible response options), and 12.5% for

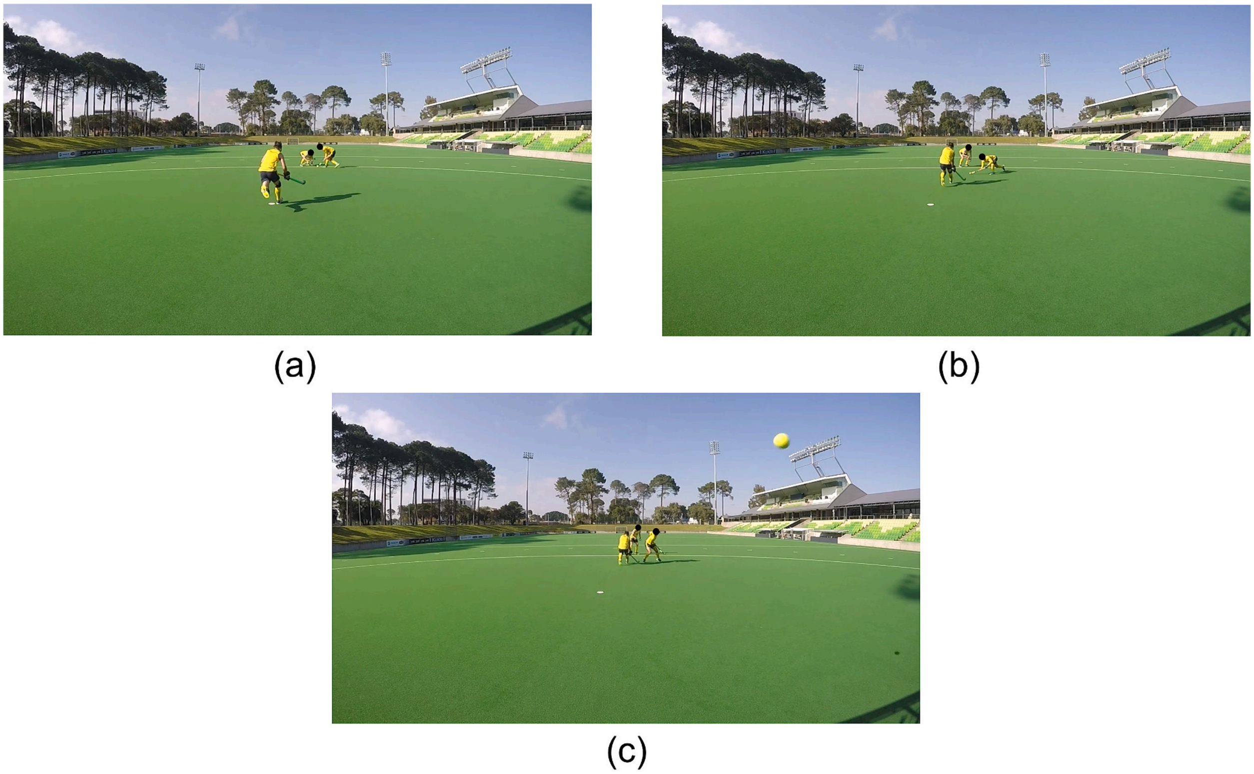

Fig. 1. Final Frame Examples Prior to Temporal Occlusion in the Penalty Corner Drag-flick Anticipation Test.
Note. Temporal occlusion occurred at (a) the point when the defending runner reached the penalty spot (Run; contextual information), and at (b) stick-ball release (Stick-Ball; contextual and kinematic information). A control condition (c) was also included with no occlusion (Ball flight), which provided all advance (contextual and kinematic) and ball flight information.

tight run and goal location (i.e., possibility of two run types × four goal locations = 8 possible response options). In the case of the primary dependent variable, each participant completed 24 trials for the loose run and 16 trials for the tight run at each temporal occlusion condition. A-priori power analysis was conducted in G-Power with $\alpha = 0.05$, 80% power, and a 95% confidence interval, which indicated that 24 and 16 trials for each participant could detect small effects of 0.19 and 0.28 (Hedges *g*), respectively. Assumptions of binomial tests were checked and met according to Russo (2004). As this study was the first of its kind in terms of investigating individual differences in perceptual anticipation, alpha level for binomial tests was set at 0.05 (Hopkins, Marshall, Batterham, & Hanin, 2009; Perneger, 1998). To complement the binomial test, effect sizes of each participants' predictions at each occlusion condition were calculated as absolute percentage differences from the respective guessing level (Cumming, 2014). In addition, where necessary, to further identify differences between participants at each occlusion condition, absolute percentage difference effect sizes were calculated. Magnitude-based inferences are more informative for identifying the size and practical significance of an effect than relying solely upon statistical significance (Batterham & Hopkins, 2006; Cumming, 2014; Wilkinson, 2014).

1.2. Results and Discussion

Figs. 3 and 4 plot each goalkeepers' prediction accuracy for loose run and goal location, as well as tight run and goal location, respectively, at each temporal occlusion.

1.2.1. Prediction of Loose Run and Goal Location

At the stick-ball temporal occlusion, seven out of the 11 goalkeepers could anticipate loose runs and the ball's goal location above the guessing level of 8.3% (GK, 2 & 3, $p = .044$; 4, $p = .003$; 5, $p = .012$; 6 & 7, $p < .001$; 9, $p < .001$, see Fig. 3). These results reveal individual differences such that most, but not all, goalkeepers can pick-up some contextual and kinematic information to anticipate. The capability to integrate information sources, however, did not appear to be dependent upon higher level of participation. For example, goalkeeper 9, who competes at national level, outperformed goalkeepers 2 and 3, who compete at international level (i.e., effect size difference of 29%, see Fig. 3).

Although some participants could anticipate above guessing level, percentage correct ranged from 21% to 50% at the stick-ball temporal occlusion. Table 1 presents more fine-grained detail of the perceptual cause of individual differences in goalkeepers' anticipation. First, each goalkeeper appears more accurate at anticipation of the loose run in isolation, than goal location in isolation. This could be because defensive runner positioning is more salient than drag-flicker kinematics. Second, there is a trend that higher or lower accuracy in prediction of loose run and goal location in isolation, which indicates attention to contextual and kinematic information, in turn results in superior (e.g., GK 9 & 4) or inferior (e.g., GK 1) integrated anticipation, respectively (see Table 1). Accordingly, it appears that goalkeepers who can more accurately identify loose runs and goal locations in isolation have more opportunity to integrate both on the same trial (e.g., see GK 9, Table 1). Collectively, these results indicate that all goalkeepers have greater difficulty in the pick-up of kinematic compared to contextual information to anticipate. Furthermore, some goalkeepers have difficulty with pick-up of loose runs to anticipate. It is important, however, to point out here that our anticipation task was more challenging with 12 and 8 response options for loose and tight run, respectively, compared to previous work in field hockey goalkeeping that included 4 response options (Baker et al., 2009). Therefore, our task is highly representative of the multiple options faced by goalkeepers under match conditions.

In the run temporal occlusion condition, two of the expert, and one of

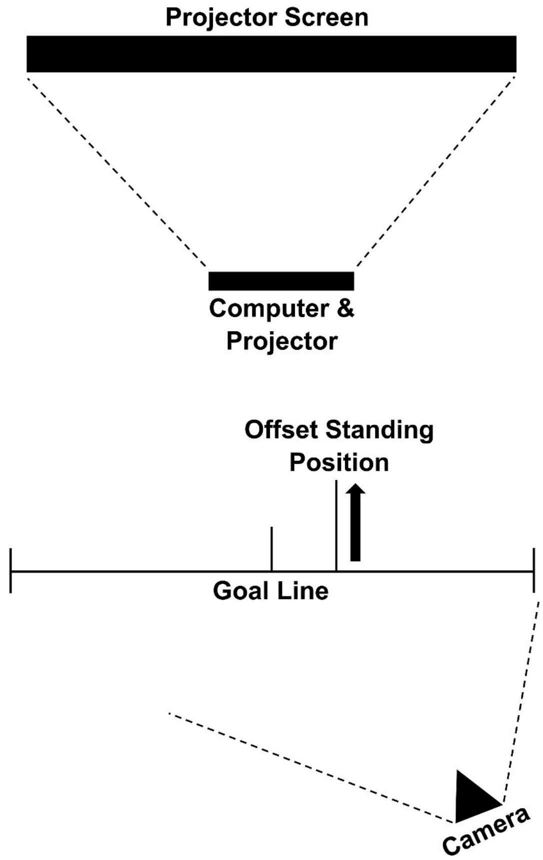

Fig. 2. Experimental Setup for Video-Based Temporal Occlusion Test and Training.
Note. Participants stood at the offset position on the goal line facing the projector screen.

the emerging-expert goalkeepers, could anticipate loose run and goal location above the guessing level of 8.3% (GK, 3, $p = .003$; 4, $p = .012$; 6, $p = .044$, see Fig. 3). This suggests some goalkeepers can use information from the defensive runner coinciding with drag-flicker ball collection onto their stick from the trapper to anticipate. These goalkeepers maintained above chance prediction at stick-ball occlusion (see Fig. 3). At the ball flight condition, all goalkeepers anticipated loose run and goal location above the guessing level of 8.3% (*ps* < .001, see Fig. 3). This indicates that all goalkeepers rely heavily on ball flight information, which may compromise their capability to save a goal because of the severe time constraints.

1.2.2. Prediction of Tight Run and Goal Location

At stick-ball temporal occlusion, seven out of the 11 goalkeepers were able to predict tight runs and the ball's goal location above the guessing level of 12.5% (GK, 3, $p = .002$; 4 & 10, $p = .041$; 7, 8, 9 & 11, $p = .010$, see Fig. 4). Again, these results reveal individual differences in the capability to integrate contextual and kinematic information in order to anticipate. Like loose run, the capability to integrate contextual and kinematic information did not appear to be dependent upon higher level of participation. For example, goalkeeper 8 and 11 are emerging-expert goalkeepers that compete at national level, yet their anticipation was higher than goalkeeper 1 and 2, who compete at international level (i.e., effect size difference of 13%, see Fig. 4).

Similar to the loose run, anticipation of tight run and goal location did not exceed 50%, ranging between 31% and 44% for those goalkeepers who were significantly above the guessing level. Moreover, Table 1's fine-grained analysis revealed similar trends to the loose run, that is; higher anticipation accuracy of tight runs in isolation compared to goal location in isolation, as well as more frequent pick-up of tight run and ball location in isolation that provides greater opportunity to integrate both for above chance prediction (e.g., see GK 3, Table 1). Overall, integration of contextual and kinematic information to anticipate appears as difficult for tight runs as is it for loose runs.

At the run temporal occlusion condition, five goalkeepers were able to anticipate tight runs and goal locations above the guessing level of 12.5% (GK, 1 & 11, $p = .010$; 2, 3 & 7, $p = .041$, see Fig. 4). Given a similar observation for loose run, it appears some goalkeepers can integrate runner and drag-flicker ball collection for above chance prediction. Not all goalkeepers, however, could maintain prediction above guessing to the stick-ball occlusion, with GK 1 and 2, but not GK 3, 7, and 11, scoring below guessing (see Fig. 4). All goalkeepers anticipated tight runs and goal location above the guessing level of 12.5% (*ps* < .001) at the ball flight temporal occlusion, indicating again, heavy reliance on

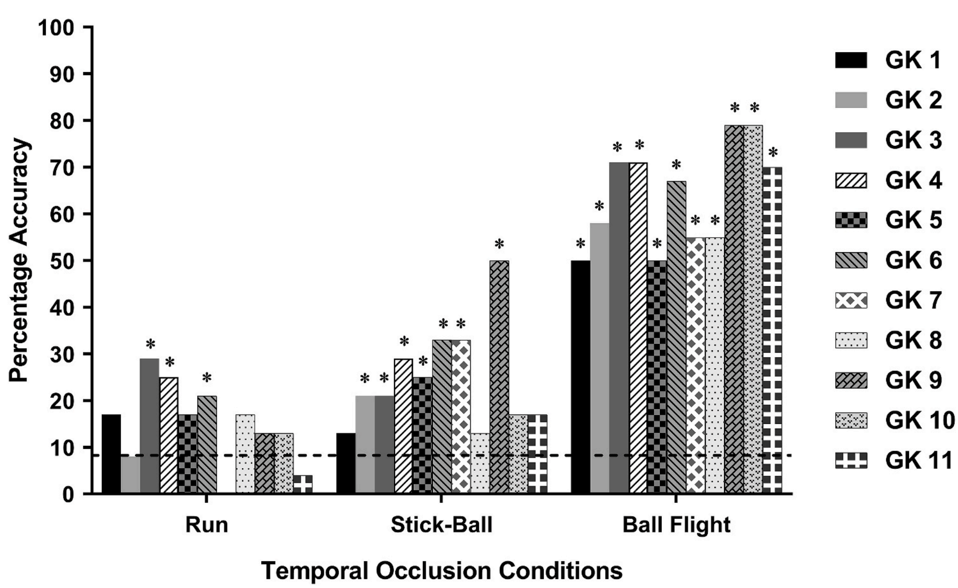

Fig. 3. Goalkeepers' Absolute Percentage Accuracy for Loose Run and Goal Location Combined at the Temporal Occlusion Conditions.
Note. Horizontal line indicates guessing level of 8.3%. Asterisks indicates prediction above guessing level ($p < .05$). Error bars are not plotted, as these are absolute values. Absolute percentage effect size difference from guessing is embedded as part of absolute percentage correct.

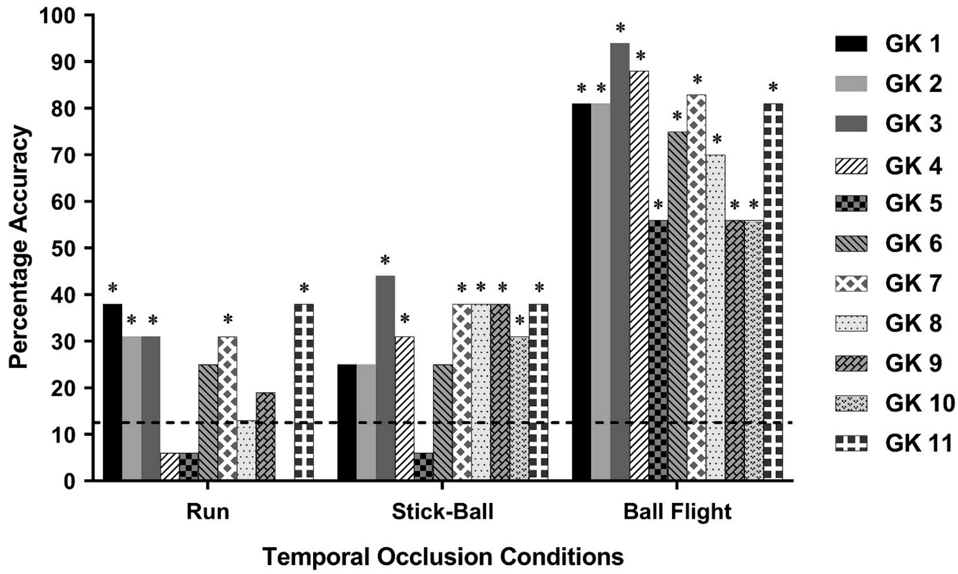

Fig. 4. Goalkeepers' Absolute Percentage Accuracy for Tight Run and Goal Location Combined at the Temporal Occlusion Conditions.
Note. Horizontal line indicates guessing level of 12.5%. Asterisks indicates prediction above guessing level ($p < .05$). Error bars are not plotted, as these are absolute values. Absolute percentage effect size difference from guessing is embedded as part of absolute percentage correct.

Table 1
Goalkeepers' Percentage Correct Anticipation of Run Type, Goal Location, and Run Type and Goal Location Combined for Loose and Tight Runs at the Stick-Ball Temporal Occlusion Condition, Across Video Test phases in Experiments 1 and 2.

Goalkeeper	Loose Run									Tight Run								
	Exp.1 - Test			Exp.2 - Re-test			Exp.2 - Retention			Exp.1 - Test			Exp.2 - Re-test			Exp.2 - Retention		
	RC	LC	R&L (/24) %	RC	LC	R&L (/24) %	RC	LC	R&L (/24) %	RC	LC	R&L (/16) %	RC	LC	R&L (/16) %	RC	LC	R&L (/16) %
1	38	29	(3) 13	88	46	(9) 38*	92	33	(8) 33*	88	31	(4) 25	75	25	(3) 19	88	19	(3) 19
2	67	38	(5) 21*	92	33	(6) 25*	96	50	(11) 46*	94	25	(4) 25	63	44	(4) 25	56	38	(4) 25
3	75	38	(5) 21*	83	54	(10) 42*	83	46	(9) 38*	88	56	(7) 44*	94	50	(7) 44*	100	63	(10) 63*
4 (Control)	83	33	(7) 29*	92	38	(8) 33*	50	29	(6) 25*	94	38	(5) 31*	75	44	(5) 31*	94	19	(2) 13
5 (Control)	42	29	(6) 25*	54	29	(3) 13	38	29	(1) 4	44	25	(1) 6	50	13	(1) 6	88	25	(4) 25
6	88	33	(8) 33*	–	–	–	–	–	–	56	38	(4) 25	–	–	–	–	–	–
7	79	42	(8) 33*	–	–	–	–	–	–	94	38	(6) 38*	–	–	–	–	–	–
8	54	17	(3) 13	–	–	–	–	–	–	69	50	(6) 38*	–	–	–	–	–	–
9	96	50	(12) 50*	–	–	–	–	–	–	75	38	(6) 38*	–	–	–	–	–	–
10	83	25	(4) 17	–	–	–	–	–	–	81	31	(5) 31*	–	–	–	–	–	–
11	79	17	(4) 17	–	–	–	–	–	–	69	38	(6) 38*	–	–	–	–	–	–

Note. RC = absolute percent run correct. LC = absolute percent goal location correct. R&L = absolute correct run and goal location out of the 24 and 16 trials at stick-ball temporal occlusion (loose and tight) and respective percentage. Asterisks indicates predictions above the guessing level of 8.3% for loose run and location correct, and 12.5% for tight run and location correct ($p < .05$). Goalkeepers 6 – 11 did not partake in re-test and retention phases.

later occurring visual information (see Fig. 4). Collectively, there is justification for temporal occlusion training to help facilitate pick-up of advance information for anticipation that can provide more time to respond when saving a goal.

2. Experiment 2

Experiment 1 revealed that some goalkeepers could pick-up contextual and kinematic information, but integration of this information to anticipate was challenging. This is concerning because goalkeepers are faced with complex multiple player information and high-time constraints. They also have limited opportunity to train penalty corner defense on pitch due to the concern that shots on goal may injure defensive runners (Morris-Binelli et al., 2020). Further, they are unable to practice against drag-flickers they will face in competition (Morris-Binelli et al., 2020). Video-based temporal occlusion training provides a low cost and technologically less demanding way to deal with these challenges. Therefore, the specific purposes of experiment 2 were to investigate whether; (a) video temporal occlusion training could improve integration of contextual and kinematic information for anticipation (i.e., across experiment 1 to 2), and (b) improvements from video temporal occlusion training would be retained and transfer to the field as well as competition settings (experiment 2). It was hypothesized that: (i) there would be individual improvements in the capability of goalkeepers who received the intervention to integrate contextual and kinematic information for anticipation, with no improvement for control goalkeepers, and (ii) there would be individualized retention and transfer for some goalkeepers that received the intervention, but not for the control goalkeeper.

2.1. *Method*

2.1.1. *Participants*

Some participants in experiment 1 resided across Australia, so a sub-sample of five goalkeepers ($M_{age} = 29$, $SD = 1.41$) from experiment 1, who resided in the lead institutions state (province) participated in experiment 2. Such geographical restrictions that limit access to truly expert athletes for extended periods of time is common in sports with international high-performance training centers (Müller, Brenton, & Rosalie, 2015). The sub-sample consisted of the four expert goalkeepers who played at international level and one emerging-expert goalkeeper who played at national level. As in experiment 1, the video and field-based tests employed in experiment 2 were powered based upon an individual trial basis (see training instrument validation and statistical analyses sections for relevant details).

2.1.2. Experimental Design, Instruments, and Procedure

Due to the accessible sample size and the reluctance of expert coaches to allow only some of their athletes to receive an intervention (Panchuk, Klusemann, & Hadlow, 2018), observational type designs were employed. Accordingly, video test, re-test, and retention, with a field pre- and post-test, as well as a within-subject repeated-measures competition transfer assessment, all at the individual participant level, were implemented (e.g., see Brenton, Müller, & Harbaugh, 2019). The intervention consisted of video-based temporal occlusion training including in-match footage of opposition penalty corners. Video test results from experiment 1 were used as a pre-test. Three of the expert goalkeepers received the intervention, while the remaining expert and emerging-expert goalkeepers did not and acted as controls. Participants completed the video re-test a week after conclusion of the intervention and six months later as a retention test. As the expert control goalkeeper was not available to complete the field transfer tests, the emerging-expert goalkeeper was the sole control participant for this component. Further, only two of the expert goalkeepers had match statistics before and after the intervention. Accordingly, their match statistics were gathered over two time points before the intervention (baseline 1 and 2) to act as a control phase, as well as after training (post-test), to assess transfer to competition. All participants partook in standard field hockey practice and matches, with none involved in any other form of visual training during the study.

Training Instrument Design and Validation. Prior to in-match filming of penalty corners from a crossbar view for design of temporal occlusion training stimuli, anticipation scores between viewing perspectives was compared. During filming of experiment 1, a second GoPro was placed on the crossbar of the goal in the same offset position to the in-goal camera (see Fig. 5). This camera view could also capture the defensive runner, trapper and drag-flicker shot on goal. Footage from the crossbar view was used to create a temporal occlusion test, as per experiment 1 in-goal view. Due to restriction upon participant time, the crossbar test included the same combinations of runs, goal locations and temporal occlusions, but was limited to two unique versions, totaling 60 trials. Four expert goalkeepers completed the crossbar temporal occlusion test two months after experiment 1 video test. Anticipation on the crossbar and in-goal (experiment 1) tests for the same 60 trials were compared. Individual goalkeeper percentage accuracy at each occlusion condition was collapsed together for analysis. A-priori power analysis was conducted in G-Power with $\alpha = 0.05$, 80% power, and a 95% confidence interval, which indicated that for loose run and goal location combined, 96 trials at each occlusion condition could detect a small effect ($w = 0.29$). For tight run and goal location combined, 64 trials at each occlusion condition could detect a moderate effect ($w = 0.36$). Chi-square tests indicated there was no significant difference in the proportion of percentage correct for loose run and goal location combined between the in-goal and crossbar tests at; Run [in-goal: 15%, crossbar: 19%; χ^2 (1) = .30, p = .584], Stick-Ball [in-goal: 29%, crossbar: 27%; χ^2 (1) = .05, p = .820], and Ball Flight [in-goal: 67%, crossbar: 75%; χ^2 (1) = .81, p = .369] temporal occlusion conditions. There was also no significant difference in the proportion of percentage correct for tight run and goal location combined between the in-goal and crossbar test at; Run [in-goal: 38%, crossbar: 34%; χ^2 (1) = .07, p = .794], Stick-Ball [in-goal: 34%, crossbar: 28%; χ^2 (1) = .29, p = .590], and Ball Flight [in-goal: 94%, crossbar: 88%; χ^2 (1) = .74, p = .672] temporal occlusion conditions. These results indicate that viewing the penalty corner from the hockey goal's crossbar does not impede anticipation.

Temporal Occlusion Training Stimuli. A high-speed GoPro was positioned on each goal's crossbar at international and national matches to capture penalty corners. Later, an expert field hockey goalkeeping coach viewed each penalty corner to determine whether the lead defending runner had executed a tight or loose run, and the hockey ball's goal location (i.e., locations 1 to 6, as per video test of experiment 1). Only direct drag-flicks at goal and no deflections or hits were chosen as stimuli. Thirty-seven penalty corners consisting of 20 different drag-flickers, 24 tight runs, 13 loose runs, and drag-flicks to each of the six goal locations, were used to create temporal occlusion training stimuli. The two drag-flickers in experiment 1 video test were not included in the training stimuli. As the focus was to improve integration of contextual and kinematic information to anticipate, temporal occlusion was applied at stick-ball release, 80 ms after stick-ball release or there was no occlusion, like previous literature (Baker et al., 2009; Brenton, Müller, & Dempsey, 2019).

Training Procedures. Intervention goalkeepers received three sessions of video occlusion training per week for a four-week period, plus a final session at the beginning of the fifth week. The video training consisted of 4 (locations out of 1 – 4 goal targets) × 2 (temporal occlusion conditions) × 2 (replications) for tight runs + 4 (locations out of

Fig. 5. Example of the Final Frame Prior to Stick-Ball Temporal Occlusion in the Crossbar View Anticipation Test.

1 – 6 goal targets) × 2 (temporal occlusion conditions) × 2 (replications) for loose runs totaling 32 trials per session. This volume of trials enabled the training sessions to be incorporated into the high-performance program alongside standard hockey practice. When creating each session from the pool of 37 match penalty corners, it was ensured that the distribution of drag-flicks to the goal locations was even across the 13 training sessions. Each of the match penalty corners was presented approximately three times across the 13 training sessions. Further, a penalty corner was not repeated until at least two sessions had passed to reduce familiarity and challenge the goalkeepers. As the 37 match penalty corners consisted of 20 different drag-flickers, each training session contained at least five different drag-flickers.

Training sessions were structured to progressively challenge participants and guard against disengagement due to task difficulty by presenting less ball flight information in a blocked to random schedule (Brenton, Müller, & Dempsey, 2019). At the beginning of the first session, participants viewed familiarization trials of each run type and goal location to orient themselves to the match footage. Thereafter, training sessions one to three included equally blocked trials of no occlusion, followed by temporal occlusion 80 ms after stick-ball release. Sessions four to six included equally blocked trials occluded 80 ms after stick-ball release, followed by stick-ball release temporal occlusion. Sessions seven to nine contained a randomized sequence of trials temporally occluded at 80 ms after and at stick-ball release. Sessions 10 to 13 included trials temporally occluded only at stick-ball release. Like experiment 1, participants watched the projected footage in a sports-specific stance and verbalized their response (Panchuk et al., 2018), which was recorded by a GoPro. Immediately afterwards, participants were given feedback by the run type and goal location presented on the screen, followed by an unoccluded version of the previous training trial. Each training session was completed individually and took approximately 15 minutes.

Re-Test, Retention, Transfer, and Competition Performance Procedures. The test procedures for the video re-test and retention were the same as experiment 1.

The in-situ field transfer test was designed to correspond to perceptual information in the video test, but required goalkeepers to save the drag-flicks on goal. On an international field hockey pitch, three synchronized high-speed cameras (GoPro model HERO6 Black) sampling at 120 frames-per second were positioned around the penalty circle (see Fig. 6). In the pre- and post-transfer-tests, each goalkeeper faced 20 penalty corner drag-flicks consisting of; 4 (goal locations: 1 – 4) × 2 (replications) for tight runs + 6 (goal locations: 1 – 6) × 2 (replications) for loose runs. To minimize potential injury, penalty corners were performed by multiple injectors, trappers, defending runners, and a pool of drag-flickers who played at international level for Australia, with a limitation imposed upon trial numbers by coaching staff, which is common in elite sport (Müller, Brenton, & Rosalie, 2015). On each test trial, the defensive runner and drag-flicker were instructed from a predetermined randomized matrix to execute the run type and shot on goal, respectively. An expert field hockey coach was present to verify whether the skills were executed correctly. If a trial was not completed successfully, the next trial on the matrix was completed and the unsuccessful trial was repeated later. Each individual testing session took approximately 15 minutes to complete.

In relation to competition performance, the number of saved penalty corner drag-flicks for each goalkeeper were sourced from the team analyst. These match statistics were taken from international tournaments, which featured top 10 ranked teams, across the 2017 and 2018 seasons. The tournaments used in each goalkeeper's baseline 1 and baseline 2 measurements was dependent on the amount of drag-flicks each goalkeeper faced per match. The number of saved drag-flicks in 2018 tournaments directly post-intervention were used for both goalkeeper's post-test. Only direct drag-flicks that arrived at the goal unobstructed and required a save by the goalkeeper were included for analysis. Goalkeeper 2 faced 8, 13, and 4 penalty corner drag-flicks at baseline 1, baseline 2, and post-test, respectively. Goalkeeper 3 faced 8, 5, and 5 penalty corner drag-flicks at baseline 1, baseline 2, and post-test, respectively.

2.1.3. *Dependent Measures and Statistical Analyses*

The dependent variables and statistical analyses for the video re-test and retention were the same as experiment 1. The exception was that absolute percentage change effect sizes were calculated for each goalkeeper to identify anticipation performance improvement between test phases, at stick-ball temporal occlusion. This was to further identify improvement in the integration of advance cue contextual and kinematic information.

The in-situ test included three dependent variables at the individual

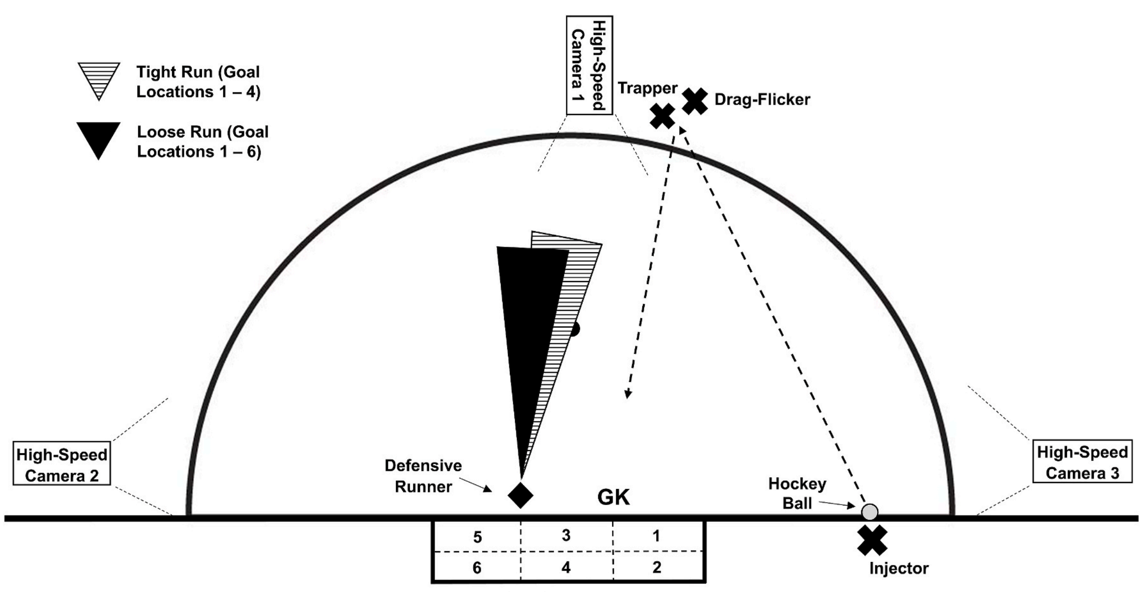

Fig. 6. In-Situ Field Test Player and Equipment Set-Up.
Note. Goalkeepers (GK) stood at the offset position on the goal line and attempted to save penalty corner drag-flicks. The defensive runner executed tight runs with drag-flicks executed to four goal locations (i.e., 1 – 4), or loose runs with drag-flicks executed to six goal locations (i.e., 1 – 6).

participant level: (i) absolute response accuracy, which was defined as the percentage of successful goals saved (e.g., Müller et al., 2017), (ii) error distance, which was defined as the mean estimate distance (cm) between the ball and the saving limb (i.e., arm or leg; Müller & Abernethy, 2008), and (iii) response initiation time, which was defined as the mean initiation of the final definitive movement of the arm or leg in the direction of the hockey ball to save the goal (Abernethy, 1984). In relation to response accuracy, a previously validated scale (Müller & Abernethy, 2008) was adapted to categorize performance as follows: (a) save (i.e., contact made with the ball resulting in no goal), (b) unsuccessful contact (i.e., contact made with the ball, but a goal was scored), and (c) miss (i.e., no contact made with the ball resulting in a goal). All dependent variables were analyzed in Kinovea (version 0.8.27) software using a frame-by-frame analysis, with synchronized front- and side-on camera angles to determine save and error values, with definitive movement time calculated from stick-ball release. The point of stick-ball release was considered time zero, with positive values indicating definitive movement after stick-ball release. An approximation of average ball speed of the drag-flicks was also calculated for each goalkeeper. This was done by applying the following formula: speed (m/s) = distance from penalty spot to goalkeeper (5.3 m), divided by the ball transit time from penalty spot until the instant of glove/stick/foot contact or where the ball was in line with the goalkeepers body (in ms), and converted to km/h (Müller, Brenton, Dempsey, et al., 2015).

Linear Mixed Model (LMM) analyses with time (i.e., pre- and post-test) as a fixed effect and each goalkeeper as a random effect were run to determine individual change in dependent variables over test phases (Müller et al., 2017). If ball velocity varied across participants and test phases, it was included as a covariate in the analysis. Run types and goal locations were collapsed for each goalkeeper across test phases when running all analyses, with statistical significance set at $\alpha = 0.05$. A-priori power analysis was conducted in G-Power with $\alpha = 0.05$, 80% power, and a 95% confidence interval for individual participant change across testing phases. This indicated that for 40 trials per participant, the field test was powered to detect a moderate effect ($d = 0.40$). To complement the LMM analysis for response accuracy, the odds ratio was calculated relative to the overall model, with absolute score difference effect sizes calculated for individual change in response accuracy over test phases (Müller et al., 2017). In relation to error and movement initiation LMM, two effect sizes were calculated. The first effect size was calculated by dividing pre-to-post-test change by the standard deviation of the residual, which is essentially similar to Cohen's *d* (Feingold, 2015). The second effect size calculated was the mean score difference for each goalkeeper across test phases (Cumming, 2014).

The dependent variable for competition transfer assessment was absolute response accuracy for each goalkeeper in each assessment phase, which was defined as the percentage of successful goals saved. Due to the small number of direct drag-flicks for each goalkeeper, descriptive statistics and absolute score difference effect sizes across baseline 1, baseline 2, and post-test are reported.

2.2. Results and Discussion

2.2.1. Video Re-Test and Retention

Table 1 presents each goalkeeper's absolute percentage accuracy improvement of anticipation for tight and loose runs at the stick-ball temporal occlusion across test phases.

Loose Run and Goal Location. Binomial tests indicated goalkeeper 1 improved anticipation of loose run and goal location from chance level prediction at test (experiment 1), to significantly above the guessing level at re-test ($p < .001$, ES = 25%). Closer inspection of goalkeeper 1's prediction, revealed effect size improvements of 50% and 17% for loose run and goal location in isolation, respectively. Furthermore, effect size indicated that goalkeeper 3 improved 21% for loose run and goal location across test to re-test, with re-test anticipation remaining above chance ($p < .001$). For this goalkeeper, the intervention improved pick-up of kinematic information (goal location) in the order of a 16% effect size. Goalkeeper 2 who received the intervention and both control goalkeepers, did not show any marked improvement. Goalkeepers 2 and 4 (control), however, maintained their prediction above chance at re-test (*ps* < .05), but control goalkeeper 5's anticipation decreased to guessing at re-test ($p > .05$). These findings indicate that the magnitude of improvement in anticipation due to temporal occlusion training can vary relative to the individual, but the intervention facilitated integration of contextual and kinematic information to anticipate.

Intervention goalkeepers 1 and 3 appeared to maintain their capability to integrate contextual and kinematic information to anticipate across re-test to retention phases, with prediction above guessing level (*ps* < .001). In contrast, control goalkeepers 4 and 5 remained stable with prediction above ($p = .012$) and at ($p = .396$) guessing level, respectively (see Table 1). Accordingly, it appears the benefits of temporal occlusion training is long lasting for this component of prediction. Interestingly, goalkeeper 2, who did not improve across test to re-test phases, showed an effect size improvement of 21% across re-test to retention, with anticipation above guessing level ($p < .001$). This tentatively suggests that the training may, for some, have a delayed effect on the capability to integrate contextual and kinematic information for anticipation.

Tight Run and Goal Location. None of the goalkeepers who received the intervention improved their capability to anticipate across test to re-test phases. That is, binomial tests indicated that their prediction of tight run and goal location remained at guessing (GK 1 & 2, *ps* > .05) or at the same score above guessing (GK 3, $p = .002$) at re-test. These findings suggest that additional temporal occlusion training is needed to improve prediction of tight runs, as these may be more difficult to discriminate compared to loose runs. Given the lack of improvement in tight run and location anticipation, it difficult to determine degree of retention. Nonetheless, goalkeeper 3 seemed to exhibit a delayed training benefit with an effect size improvement of 19% across re-test to retention. Control goalkeepers' anticipation decreased to (GK 4), or remained at (GK 5), guessing level at the retention phase (*ps* > .05).

2.2.2. Field Transfer Test

Ball Speed. Table 2 presents descriptive data for average drag-flick speed for test phases and individual goalkeeper. LMM indicated that there was a significant difference in ball speed across the test phases, $p < .001$. Consequently, ball speed was included as a covariate in the LMM analyses for each dependent variable.

Response Accuracy. Fig. 7 (a) presents absolute percentage accuracy for each participant across test phases. A first LMM including the control goalkeeper indicated that overall there was no significant change in response accuracy across test to re-test phases ($p = .281$). The odds ratio, however, indicated that the odds of a successful save was 47.03% higher in the post- compared to pre-test. A second LMM run with the control goalkeeper omitted indicated an odds ratio of 71.59% for successful saves in the post- compared to pre-test, despite a lack of significance ($p = .212$). Absolute score effect size differences across pre- to post-test indicated the intervention improved save performance by 22%, 5%, and 10% for goalkeeper's 1, 2, and 3, respectively, while the control goalkeeper did not improve.

Table 2
Average Ball Speed Relative to Goalkeepers.

Goalkeeper	Speed (km/h)	
	Pre-test *M* (*SEM*)	Post-test *M* (*SEM*)
1	106.10 (1.53)	111.66 (1.34)
2	112.19 (1.92)	121.09 (1.59)
3	113.10 (2.30)	113.72 (1.07)
5 (Control)	108.83 (1.50)	110.08 (1.42)

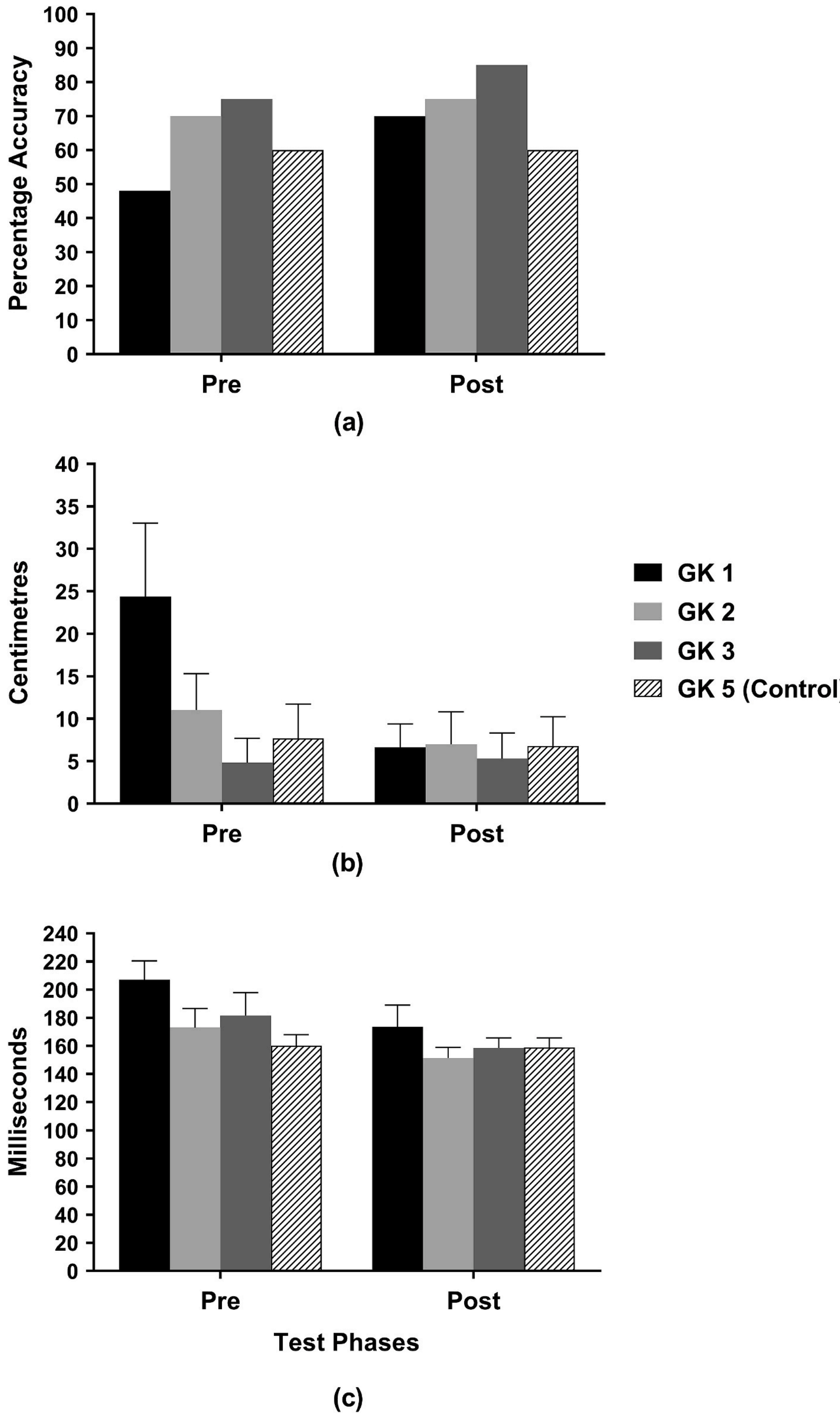

Fig. 7. Each Participant's Field Test Results Relative to Test Phases for (a) Absolute Percentage Accuracy, (b) Mean Error Distance, and (c) Mean Response Initiation Time.
Note. Error bars for (a) are not plotted as these are absolute values, but for (b) and (c) indicate standard error of the mean.

Error Distance. Fig. 7 (b) presents mean error distance for each goalkeeper across test phases. LMM indicated that overall there was no significant change in error distance to ball across pre- to post-test, χ^2 (1) = 2.31, p = .064, but there was a small effect size improvement (d = −0.25). Mean score difference effect sizes indicated a decrease in error of 17.79 cm and 4.02 cm across test phases for goalkeeper 1 and 2, respectively. Goalkeeper 3 and 5 (control) had minimal changes of 0.48 cm and 0.88 cm, respectively, across test phases.

Initiation of Definitive Movement. Fig. 7 (c) presents mean response initiation time for each participant across test phases. LMM indicated there was a significant change in response initiation across test phases, χ^2 (1) = 3.82, p = .025, with a small effect size (d = −0.32).

Goalkeeper's 1, 2, and 3 initiated their definitive movement earlier in the post-test compared to pre-test, with mean score difference effect sizes of −33.56 ms, −21.55 ms, and −22.97 ms, respectively. Control goalkeeper's movement initiation time stayed stable (ES = −1.24 ms).

Collectively, these findings indicate that the intervention had some benefits to in-situ performance in terms of getting closer to the ball, saving goals, and earlier initiation of the definitive movement.

2.2.3. Match Transfer

Fig. 8 plots match percentage accuracy for each goalkeeper across the three assessment periods. Absolute score effect size differences from baseline 1 to baseline 2 were −6% and 5% for goalkeeper 2 and 3, respectively. Absolute score effect size differences from baseline 2 to post-test were 31% and 20% for goalkeeper 2 and 3, respectively. These results provide tentative evidence that the intervention may have had some benefit to match performance.

3. Discussion

In two interconnected experiments, individual differences in anticipation performance, as well as learning, retention, and transfer were investigated in international and national field hockey goalkeepers. The sample of truly expert goalkeepers had played the game on average for 13 years and some had extensive experience representing Australia at international level. In experiment 1, our temporal occlusion test was capable of identifying individual differences in how truly expert goalkeepers use contextual and kinematic information to anticipate the drag-flick. In experiment 2, a unique opportunity was available to implement a temporal occlusion training intervention with expert athletes, which revealed that some improvements can be achieved in highly trained athletes over a relatively short period of time. The findings of these experiments are consistent with the hypotheses and contribute to theoretical understanding of anticipation and practical application in high-performance sport.

In experiment 1, we reported two main findings in relation to individual differences in anticipation within a pool of international and national goalkeepers. First, there was evidence that higher anticipation scores were not necessarily related to higher level of participation. While there are no directly comparable studies, there is evidence in the broader anticipation literature that lesser skilled performers can at times outperform higher skilled performers in video-based occlusion tests (Müller, Abernethy, & Farrow, 2006). A possible explanation for this finding is that progression to expert status has been commonly viewed as linear (Chase & Simon, 1973; Ericsson, Krampe, & Tesch-Römer, 1993), which may not necessarily be the case in terms of perceptual expertise. Another explanation is that superior perceptual-motor skill can be due to faster movement time, better capability to pick-up visual cues, or both combined (e.g., Müller, Brenton, Dempsey, et al., 2015). An individual differences approach, as used in this paper, however, has the fine-grained capacity to capture the highly individualized nature of expertise that can be masked by group designs (Müller et al., 2006; Woods, McKeown, Shuttleworth, Davids, & Robertson, 2019). To this, there is related evidence that within skilled athletes, perceptual skills such as decision-making can be differentiated into sub-groupings (Piggott, Müller, Chivers, Cripps, & Hoyne, 2019), indicating that perceptual expertise is not homogenous. Another possible reason for individual differences could be that whilst goalkeepers place importance on advance cues, some have been consistently advised to focus solely upon ball flight, and have developed their perceptual-motor skill predominantly through practice against ball projection machines (Morris-Binelli et al., 2020). There is evidence to indicate that ball projections machines alter perceptual-motor responses (Pinder, Davids, Renshaw, & Araújo, 2011), which may have influenced individual expert player anticipation on our test.

Second, the cause of individual differences in anticipation appeared due to poorer pick-up of contextual, and more so kinematic, information in isolation that presented less opportunity to integrate these sources in order to anticipate. Previous literature has, however, reported that skilled cricket batsmen can integrate earlier available contextual information (i.e., field-placing and game score) with later bowler kinematic information to anticipate ball location (Runswick et al., 2018). It is possible that in our study, goalkeepers who have previously reported to rely heavily upon ball flight (Morris-Binelli et al., 2020), may not have considered, and in turn, attended to their own defensive runner, who presents contextual information in the form of increased goal shot options. In contrast, field-placings and game score in cricket, like positioning of the trapper and drag-flicker at the top of the penalty circle (Morris-Binelli et al., 2020), may be more salient contextual information for selective attention. Difficulty in the pick-up of kinematic information could be because of reported limited opportunity for team on-field penalty corner practice, and again, frequent use of traditional ball projection machines that do not present advance cues (Morris-Binelli et al., 2020). Consistent with our findings, recent evidence among emerging-expert cricket batsmen has also reported that they were not able to use bowler kinematic cues to anticipate in a pre-test temporal occlusion task (Brenton, Müller, & Harbaugh, 2019). Similar to field hockey goalkeepers, cricket batters practice extensively on ball projection machines, which again, could have affected their advance cue

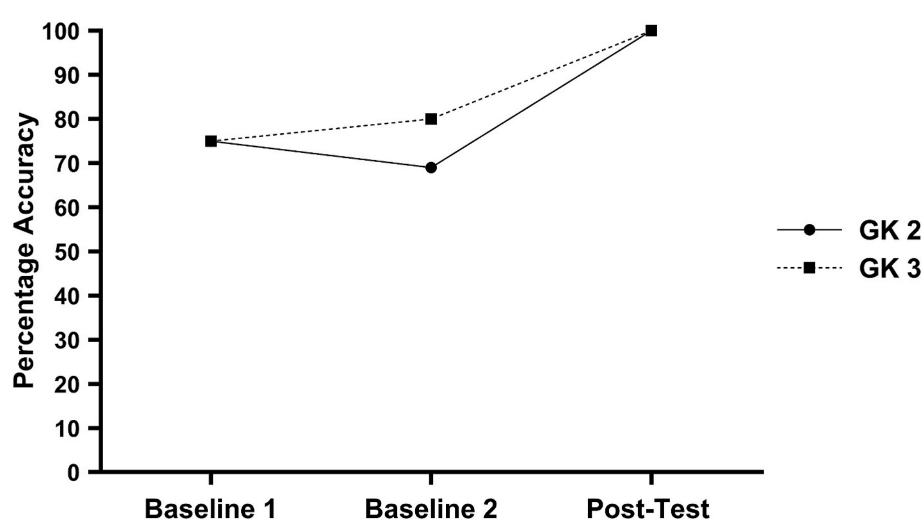

Fig. 8. Absolute Percentage Accuracy for Goalkeeper 2 and 3 Relative to Assessment Period.
Note. Error bars are not plotted as these are absolute values.

pick-up (Pinder, Renshaw, Davids, & Kerherv, 2011). Collectively, experiment 1 provided useful baseline information on individualized anticipation skill that could be targeted with temporal occlusion training.

In experiment 2, we reported several key findings in relation to individualized learning, retention, and transfer relative to video and in-situ assessments. In relation to learning on the video-test, the intervention showed individual improvements to integration of contextual and kinematic information for run type and goal location combined. These are an important finding for two reasons. First, video-based temporal occlusion training improved anticipation in some highly trained expert athletes, which has been predominantly reported to improve anticipation in skilled and novice participants (e.g., Abernethy et al., 2012; Smeeton et al., 2005; Williams et al., 2002). This indicates that there is scope to improve perceptual skill through temporal occlusion training across the skill continuum. Second, that temporal occlusion training improved integration of contextual and kinematic information for anticipation is crucial, because performers are required to deal with both sources of information in sequence within a game (Runswick et al., 2018). Our findings extend upon previous studies that have reported individualized improvement to pick-up of kinematic information (Müller et al., 2017; Scott et al., 1998), by indicating a synchronized improvement of attention to contextual and kinematic information.

In relation to retention of learning on the video test, individualized improvements appeared to be maintained over a six-month period, with some indication of individualized delayed improvement. There is very little previous evidence of the long-lasting benefits of temporal occlusion training to anticipation. A likely reason for this is that longitudinal studies are very difficult to conduct because of lack of accessibility to participants, and particularly expert performers (Morris-Binelli & Müller, 2017). Previous evidence indicates that temporal occlusion training improvement was not retained in skilled junior tennis players over a 32-day period when measured in-situ (Farrow & Abernethy, 2002), but was retained in novices over a five-month period when measure on a video-test (Abernethy et al., 2012). Skill level and mode of assessment vary across these studies, so comparison to our study is difficult. It may be that retention of perceptual learning is longer lasting, or that longer duration of training may be required for retention benefit to motor responses. This requires further investigation in future work.

In relation to transfer, some collective and individualized transfer was observed on the in-situ field test as well as to competition. For the in-situ test, improvement in accuracy of goals saved and earlier initiation of definitive movement time tended to be more collective, but improvement in error from ball position was more pronounced for one goalkeeper. Again, it is difficult to make direct comparisons to previous literature as they are group designs. Consistent with our findings, however, previous studies have reported transfer of video-based temporal occlusion training improvement from a laboratory setting to in-situ tests in terms of response accuracy (Farrow & Abernethy, 2002; Müller et al., 2017) and earlier movement initiation time (Williams et al., 2002), in non-expert athletes. Our study extends upon this literature by showing improvements to perception-action coupled in-situ tests, based on perception-only training, which demonstrates the value of video-based temporal occlusion training to expert athletes. The further suggestion of transfer to individualized improvements in competition goal saving performance post-intervention is encouraging, but needs to be considered in terms of multiple factors that may influence match play. Nonetheless, the finding of this study is in line with other group-based studies that have reported improvements in competition performance after different types of visual-perceptual training (Brenton, Müller, & Harbaugh, 2019; Vickers & Adolphe, 1997). The more evidence reported of the benefits of video-perceptual training to in-situ and competition performance, the more likely at least the latter will be accepted as a cause-and-effect relationship. Collectively, like performance findings of this study, the training study findings demonstrate that benefits to learning are relative to individual capabilities. Indeed, in the motor learning literature, recent work has revealed that acquisition of coordination patterns to improve motor skill outcomes is highly individualized and not necessarily dependent upon group-based practice structure (Pacheco & Newell, 2018).

3.1. *Theoretical and Practical Implications*

The theoretical implications of this paper refer to the model of visual anticipation in high-speed striking sports (Morris-Binelli & Müller, 2017; Müller & Abernethy, 2012). Temporal occlusion identified individual differences related to stage one of the model, where contextual and kinematic information is picked-up. That expert athletes could integrate this information to a degree, but not above 50%, was concerning because the model predicts such information pick-up allows the performer to position their body with enough time to intercept the object. Importantly, video-based temporal occlusion training provided individualized improvement to pick-up of perceptual information related to stage one of the model. This translated into improved individualized action responses, indicating that enhanced pick-up of perceptual information, as predicted in stage one of the model, is relevant to superior perceptual-motor skill performance. A future consideration for the model's prediction is that the relation between perception and action, whether performance or learning oriented, is likely to be individualized and non-linear. Therefore, the model needs to take into consideration that some experts may not necessarily be superior in their anticipation skill to emerging-experts. This provides a window of opportunity for frequent visual-perceptual training that has been lacking in the development of athletic skill. Further, as mentioned in the model (Morris-Binelli & Müller, 2017), an interdisciplinary approach incorporating factors related to sport psychology may provide a more complete understanding of anticipation performance, learning, and transfer (Morris-Binelli et al., 2020).

There are several practical implications from this paper. First, it was possible to assess pick-up of advance cue sources at the individual level in experts. This is what practitioners, such as coaches and high-performance staff want in order to individually develop athletes (Davids, Araújo, Seifert, & Orth, 2015; Reade, Rodgers, & Spriggs, 2008). Second, footage of opponent athletes can be relatively easily captured and used with temporal occlusion to train performers. Again, this is what professional athletes and coaches want in order to prepare for competition (Morris-Binelli et al., 2020). Third, both assessment and training of anticipation was done in a flexible manner that suited the busy schedule of a high-performance unit. As skill acquisition is less prominent in elite sport (Steel, Harris, Baxter, King, & Ellam, 2014), but appears to be growing in its uptake, this paper was an important step in order to demonstrate value for investment of time that did not disturb day-to-day operations of a high-performance unit. Fourth, assessment and training of anticipation was implemented in a manner that did not detract from physical practice, but allowed supplementary practice through exposure to perceptual information in the penalty corner without injury to defensive runners or physical loading on drag-flickers (Morris-Binelli et al., 2020). These implications indicate that temporal occlusion can be easily used by athletes and teams to develop perceptual expertise, which has benefit to action.

3.2. *Limitation, Future Research, and Conclusion*

There are some potential limitations that should be taken into consideration. First, accessibility to athlete time, particularly in experiment 2 was a potential limitation. It needs to be considered that due to the extremely busy competition schedule of athletes, one-month access to implement perceptual training was reasonable. Second, the number of drag-flick trials in the in-situ test is also a potential limitation. Due care, however, needed to be given to limit potential athlete injury, which may impact their capability to compete (Müller, Brenton, & Rosalie, 2015). Third, the limited number of direct match penalty corner drag-flicks is another potential limitation. It needs to be considered that direct penalty corners, which focus on the goalkeepers save capability is limited in the frequency of game goal scoring options. Fourth, the findings of improvement in anticipation across test-to-re-test and a possible delayed benefit from the intervention (experiment 2) need to be treated with some caution. This is because there can be day-to-day fluctuations in factors such as attention, fatigue, sleep, and motivation that can influence performance and learning (e.g., Smith et al., 2016). These factors can be accounted for through use of a single-subject multiple baseline design. It needs to considered, however, that multiple assessments using video and in-situ tests, where goalkeepers are exposed to the same opponents, can also create a familiarity effect. The lack of improvement of the control goalkeepers in experiment 2 provides evidence that familiarity was not a confounding factor to the learning improvements we reported. A multiple baseline design also requires increased access to participant time, which as we noted earlier was difficult to attain. In relation to tracking match statistics that does not incur upon participant time, we indeed employed a multiple baseline design where a broader range of opponents existed to minimize familiarity, which showed improvement in performance after the intervention.

Future research should consider smaller duration perceptual training phases post-retention test, if athlete anticipation improvement declines. This can form a maintenance phase for anticipation skill that has been developed through an initial larger block of temporal occlusion training. Furthermore, female goalkeepers could be included in future experiments to understand how they integrate contextual and kinematic information to anticipate. It is important to understand how female athletes anticipate under their temporal constraints, as this may present further unique opportunities to help train their perceptual-motor skill.

In conclusion, this paper identified individual differences in the anticipation skill of expert and emerging-expert field hockey goalkeepers. Thereafter, through one month of video-based temporal occlusion training, the integration of contextual and kinematic information was improved to a degree in some truly expert goalkeepers. This individualized approach to assessment and training ensured that the anticipation skills of these athletes were well prepared for competition.

Authorship contributions

Khaya Morris-Binelli: Conceptualization, Methodology, Validation, Data curation, Formal analysis, Investigation, Writing - original draft. **Sean Müller:** Conceptualization, Methodology, Validation, Data curation, Writing - original draft, Supervision. **Fleur E.C.A. van Rens:** Conceptualization, Methodology, Writing - original draft, Supervision. **Allen G. Harbaugh:** Data curation, Formal analysis, Writing - review & editing. **Simon M. Rosalie:** Writing - review & editing, Project administration

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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