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Quiet eye predicts goaltender success in deflected ice hockey shots

*DEREK PANCHUK [1,3], JOAN N. VICKERS [2], WILL G. HOPKINS [3]

[1] *Movement, Science, Australian Institute of Sport, Leverrier Street, Bruce, Canberra, Australia 2617. Phone: +61 (2)6214 1069. Email: derek.panchuk@ausport.gov.au*

[2] *Faculty of Kinesiology, University of Calgary, 2500 University Drive Northwest, Calgary, AB, Canada T2N 1N4. Phone: +1 (403) 220-3420. Email: Vickers@ucalgary.ca*

[3] *Institute of Sport, Exercise, & Active Living, Victoria University, Ballarat Road, Footscray, Melbourne, Australia 3011. Phone: +61 (3)9919 6100. Email: William.hopkins@vu.edu.au*

* Corresponding Author

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Abstract

In interceptive timing tasks, long quiet eye (QE) durations at the release point, along with early tracking on the object, allow performers to couple their actions to the kinematics of their opponent and regulate their movements based on emergent information from the object's trajectory. We used a mobile eye tracker to record the QE of eight university-level ice hockey goaltenders of an equivalent skill level as they responded to shots that deflected off a board placed to their left or right, resulting in a trajectory with low predictability. QE behaviour was assessed using logistic regression and magnitude-based inference. We found that when QE onset occurred later in the shot (950 ± 580 ms, mean ± SD) there was an increase in the proportion of goals allowed (41% vs 22%) compared to when QE onset occurred earlier. A shorter QE duration (1260 ± 630 ms) predicted a large increase in the proportion of goals scored (38% vs 14%). More saves occurred when QE duration (2074 ± 47 ms) was longer. An earlier QE offset (2004 ± 66 ms) also resulted in a large increase in the number of goals allowed (37% vs 11%) compared to a later offset (2132 ± 41 ms). Since an early, sustained QE duration contributed to a higher percentage of saves, it is important that coaches develop practice activities that challenge the goaltender's ability to fixate the puck early, as well as sustain a long QE fixation on the puck until after it is released from the stick.

Keywords: *Gaze, interceptive actions, anticipation, uncertainty, ice hockey*

Introduction

Successfully performing an interceptive action requires precisely coordinating the movements of an effector (e.g., limb, racquet, or glove) with an approaching target object (Vickers, 2007). When the object's trajectory is largely predictable, the flight path can be determined early from the moment of release. Therefore, a performer can use perceptual information from the kinematics of their opponent and the object's early flight to constrain their actions. In the case of activities that involve less predictable object flight, which occurs during cricket batting or when handling a deflection in soccer or ice hockey, perceptual information that completely specifies the point of interception does not emerge until relatively late in the object's trajectory. As a result, performers must develop perceptual-motor strategies to overcome task constraints specific to their performance environment. Research in tasks such as cricket batting (Land & MacLeod, 2000), volleyball serve reception (Vickers & Adolphe, 1997), table tennis (Rodrigues, Vickers & Williams, 2002), and ice hockey goaltending (Panchuk & Vickers, 2006; 2009) shows that elite performers develop specific patterns of gaze that allow them to perceive critical task-related information during object flight and overcome these unique demands. In the current study, we investigated the gaze strategies of ice hockey goaltenders responding to deflected shots. Deflections occur frequently in the game of ice hockey due to the number of players between the shooter and the goal. They pose a significant challenge to a goaltender because often the puck will deviate from its trajectory in unexpected ways requiring very late adjustments to coordinate a saving attempt.

Quiet eye (QE) is the final fixation prior to executing a critical movement in the task of interest (Vickers, 1996; 2007). QE research has been conducted in targeting tasks, such as golf (Vine, Lee, Moore, & Wilson, 2013) and throwing (Klostermann, Kredel, & Hossner, 2013), but we know comparatively little about QE in interceptive timing tasks that involve a late change in trajectory. The QE is a variable that has been shown to reliably distinguish saves from goals in elite goaltenders when handling shots taken in front of the net without a bounce or deflection (Panchuk & Vickers, 2006; 2009). Elite ice hockey goaltenders anchored their QE on the puck at the end of a shooter's stick for 952 ms during saves compared to less than 826 ms on goals. Similar findings have been reported in soccer goalkeeping, although, rather than having a QE located on the ball, goaltenders fixated a visual pivot located between the kicking leg and ball on successful save attempts (Piras & Vickers, 2011).

When the final trajectory of a target object has low predictability, the task of interception becomes incrementally more difficult. For example, in ice hockey, shots that deflect off a player or stick after being shot towards the net are the most difficult for goaltenders to stop. We know little about whether QE has an influence on performance in these situations due to a lack of research in the area. We do know, however, that in activities that involve a late change in object trajectory (e.g., cricket batting, tennis), a pattern of gaze has emerged characterised by fixations on the release point, an early period of tracking followed by an anticipatory saccade to the bounce point (Land & McLeod, 2000; Ripoll & Fleurance, 1988; Rodrigues, et al., 2002; Singer, et al., 1998). This may allow performers to use information emerging from the trajectory of the object to determine the angle of incidence of the approaching object and predict the angle of reflection. Recent research has suggested that, in highly skilled performers, longer periods of tracking from release to interception, without the need for an anticipatory saccade, may be possible (Mann, Spratford, & Abernethy, 2013). In relation to QE, it is possible that a late fixation at the point of deflection is a factor that discriminates level of expertise and successful performances although this may be dependent on specific task constraints.

The purpose of this study was to determine the QE of elite goaltenders in ice hockey when the puck was deflected off boards placed to the left or right of the goal. We sought to examine this question by recording the coupled gaze and motor behaviour of skilled ice hockey goaltenders as they responded to deflected shots delivered by similarly skilled shooters. Due to the speed of the puck, which in previous studies resulted in only a short period of tracking and no late tracking (Panchuk & Vickers, 2006; 2009), we did not expect a QE at the deflection point to be predictive of saves (i.e., players would saccade to the point of deflection but not fixate or track the puck, because their gaze would arrive too late). Rather, saves would be predicted by an earlier QE onset on the puck/stick region and a longer QE duration, extending into early puck flight, compared to goals and the unique task constraints present in the task (i.e., a late, unpredictable deflection) would prevent late tracking at or near the point of interception.

Methods

Participants

Eight (n = 8) elite male goaltenders with a mean age of 24.4 years (range: 22-27) participated in the study. Goaltenders were recruited from local varsity ice hockey teams, had normal or corrected-to-normal vision, had an average save percentage of 89.8% (range: 88.7–90.5) saves during the last season, and caught with their right hand. Nine (n = 9) shooters with a mean age of 25.8 (range: 23-32) were recruited for the experimental sessions. The shooters played at the same level as the goaltenders (varsity or professional level hockey experience) and shot right-handed; two shooters were used for each experimental session to minimise fatigue. All participants provided their informed consent to participate in the study and all experimental procedure were approved by the local research ethics board.

Apparatus

All testing was conducted on a regulation size ice hockey rink. The vision-in-action (VIA) system (Vickers, 1996; 2007) was used to record the coupled gaze and motor behaviours of the goaltenders and shooters. The VIA system integrated gaze input from a mobile eye tracking system (ASL Mobile Eye, Applied Sciences Laboratories, Bedford, MA) and external video of the participants' motor actions (Panasonic PV-GS200, Japan) which were synchronised at a rate of 30 Hz. For safety reasons, and to protect the eye tracker, the glasses were fitted under a modified goaltender helmet (Itech, Canada). Two deflection boards, which have been used extensively in goalie training to train goaltenders to respond to deflected puck, were custom built for the experiment (Andrews Hockey Growth Programs International). The boards were made of wood (1.2 m in length and 0.2 m high) and the outer surfaces were covered with fibreglass similar to the material that rink boards are made of. Each board was set up 2.2 m to the left or right of the goaltender at an angle of 20^o. Each board had a different angle of incline and one, with an angle of 7.5^o, was placed in line with the left post and the other, with an angle of 15.0^o, was placed in line with the right post (Fig 1). The shooters were instructed to aim at the deflection board. The type of deflection varied depending on where the puck contacted the board, the speed of the shot, and which side the shot came from (low deflection on the left and high on the right).

Procedure

Prior to beginning the experiment the goaltender was permitted as much time as they needed to warm-up. At the completion of the warm-up the goaltender was fitted with the eye tracker and helmet and then calibrated. After calibration, the goaltender was given an opportunity to get accustomed to the feel of the helmet while performing before the experimental task began.

In the experimental task goaltenders responded to both direct shots (without a bounce) and deflected shots (left and right) taken from a shooter located 10 m directly in front of the goal. Five shots were taken in a block and shooters alternated between blocks. In each block the shooter was instructed to take two shots towards the left deflector, two to the right deflector, and one directly at the goaltender in a random order at their discretion. Direct shots were used as catch trials to ensure goaltenders were not anticipating shot direction. Each shot attempt followed a similar pattern; once the shooter and goaltender were ready, a verbal command (“Go!”) was given to start the trial by the experimenter. After that command, the shooter was free to shoot the puck at any time, using a wrist shot, and the goaltender was asked to respond to the shot accordingly. Outside of these instructions, no other constraints were placed on the shooter or goaltender. A trial ended when the goaltender saved the puck or the puck entered the goal and trials were repeated if the puck missed the net or deflector board. A recorder kept track of the trials and recorded the outcome of each attempt. Shots were taken until at least five goals and five saves were recorded and testing was halted when thirty trials were completed (regardless of saves/goals); goaltenders were naive to this requirement.

Gaze and Motor Coding

Gaze and motor data were coded following the same procedures as in Panchuk and Vickers (2006; 2009) using Quiet Eye Solutions (Quiet Eye Solutions, Inc., Calgary, AB). Since trial time varied, QE behaviours (onset, offset and duration) were measured in both absolute (ms) and relative time (%). Consistent with previous research in ice hockey goaltending (Panchuk & Vickers, 2006; 2009) and to permit comparisons with that research, trial onset occurred 2000 ms prior to puck release. To determine when the QE period occurred, five sequential motor phases were coded; three from the shooter: preparation time (PT), body movement (BM), stick movement (SM), and two from the goaltender - reaction time (RT), and movement time (MT). PT occurred from the onset of the trial until the first movement of the shooters' body. BM occurred from the first movement of the body until the first movement of their stick. SM occurred from the first movement of the stick until the first frame of data where the puck leaves the shooter's stick. RT occurred from puck release until the first movement by the goaltender in a saving motion (all goaltenders in this study used a 'butterfly-style' of play where the first movement is always to drop to their knees, this resulted in their skates moving outward). MT occurred from the first movement of the goaltender until the goaltender made a save or the puck crossed the plane of the goaltender before entering the net.

Quiet eye was coded when the gaze remained within 3° of visual angle (focal vision calculated at a distance of 10 m) on a location or moving object for a minimum duration 100 ms and was offset when the gaze left that location for 100 ms. Quiet eye was the final fixation or tracking gaze located on a specific location or object in the environment within 3° of visual angle for a minimum of 100 ms prior to the first saving action of the goaltender (i.e., MT phase).

Data Analysis

Effects of measures of the goaltender's eye fixation (absolute and relative QE onset, duration, and offset) on proportion of successful shots were analysed with repeated-measures logistic regression using the generalised mixed model procedure (Proc Glimmix) in the Statistical Analysis System (Version 9.4, SAS Institute, Cary, NC). The dichotomised QE variable was the fixed effect and the goaltender's identity was the random effect in the model. The outcomes are therefore within-subject effects. Allowance was made for overdispersion. Effects were assessed via non-clinical magnitude-based inference (Hopkins et al., 2009; Hopkins, 2010). In total 172 trials were included in the analyses (53 goals, 119 saves). The analyses were originally intended to involve repeated measures ANOVA and, rather than excluding any data, all trials were analysed using logistic regression. This resulted in an uneven number of trials being recorded for each goaltender (range 15-30). The possibility of a non-linear relationship between each QE measure and the dependent variable in each logistic regression was investigated in preliminary analyses of the effect of the measure parsed into quantiles. It was evident that quartiles produced the clearest QE effects, with the highest or lowest quantile (depending on the QE measure) showing the greatest reduction in proportion of successful goals and with little difference between the other quartiles. Use of ROC curves would be another approach to identify a threshold value for dichotomizing each QE measure, although balancing sensitivity and specificity of prediction of successful saves would not necessarily maximise the effect on goal ratio. The QE effects were therefore estimated as the ratio of proportions in one quartile versus the mean of the other three. Confidence limits for the proportion ratio were converted from confidence limits for the odds ratio provided by the logistic regression.

Magnitude thresholds for the proportion ratios were developed by simulation, as follows. It was assumed that the QE effects would apply to the proportion of successful shots in ice-hockey competitions. In the 2460 matches of the 2013-14 season of National Hockey League, 9.1% of 30 goal shots per team were successful on average (data obtained from NHL.com). A spreadsheet was used to generate Poisson-distributed scores of 16,000 such matches between teams with a given proportion ratio of successful shots. Ratios for reductions in goal scoring were found that give differences of 10%, 30%, 50%, and 70% in proportions of matches won, which correspond to thresholds for small, moderate, large and very large effects (Hopkins et al., 1999; 2009); the ratios were 0.84, 0.56, 0.32 and 0.17 respectively.

Results

Results of the logistic regression and magnitude-based inference are displayed in Table **1**. The table shows the predicted proportion of successful shots (i.e., goals scored) in the upper or lower quartile (dependent on the direction of effect) in comparison to the other three quartiles (a higher % of goals = poorer performance). For determining relative time of the trial, time zero (ms, %) occurred at the beginning of the trial and the end of the trial occurred approximately 2360 ms later (100%). The results show a moderate decrease in performance (predicted % of goals) when QE onset occurs later, as well as when QE duration is shorter. There is also a large decrease in performance when QE offset occurs earlier. Shot speed was not recorded directly but, using the puck flight time, we determined that there was a high degree of consistency in shot speed on saved (361 ± 39 ms) and scored (362 ± 39) shots.

Discussion

Using logistic regression and magnitude-based inference (Hopkins, 2009; 2010) we found that QE behaviour predicted performance for goaltenders when shots were randomly deflected off deflection boards placed to the right or left of the net. Our hypotheses regarding QE behaviour were also confirmed; logistic regression predicted that an earlier QE onset and longer QE duration would result in moderate and large increases in the percentage of saves made, respectively. Somewhat unexpectedly, a later QE offset also predicted a large increase in the percentage of saves made; given that previous research has not found any differences in QE offset in an interceptive action (Panchuk & Vickers, 2006; 2009) we did not make any predictions regarding its influence on performance.

Our results suggest that, in this task, successful goaltenders read the deflection during the moment of release, and are more successful when they have a later QE offset on the puck during early flight. The QE therefore differed when the shots were deflected, as opposed to direct shots without any deflection (e.g., Panchuk & Vickers, 2006; 2009). It appears that, for ice hockey goaltenders, a QE duration with an early onset and long duration is adequate to handle direct shots because once the shot leaves the stick its trajectory will not change and additional information regarding trajectory would be redundant. For both direct and deflected shot, the early onset and long duration of the QE period in this instance affords a number of benefits for the goaltender. First, anchoring the gaze on the puck early permits them to determine when the shooter will initiate the shooting action (possibly acting as a visual pivot; Piras & Vickers, 2011). Second, maintaining gaze through the shooting action allows the goaltender to coordinate their actions relative to the actions of the shooter and the puck being released from the stick. When a deflected shot is executed, however, a later QE offset after release provides the goaltender with additional specifying information regarding the trajectory of the shot and where/when a potential deflection may occur (e.g., where it may hit the deflection board in this particular task). Given that goaltenders typically rely on a style of play where they use their body to block deflected shots (rather than a specific effector such as the glove hand), having the ability to make a definitive decision about which direction to move the body in response to visual information that arises relatively late is essential for successful performance. Although the nature of this task relative to how pucks are deflected in an actual game context may limit the generalisability of this statement.

The large increase in performance predicted by a later occurring QE offset is a pertinent finding in the context of interceptive actions. While previous studies have found a relationship between QE offset and performance they have typically used aiming tasks such as golf putting (Klostermann, Kredel & Hossner, 2014; Vine, Lee, Moore & Wilson, 2013). For interceptive tasks with predictable object flight, tracking the ball for a longer duration can be beneficial for performance (Panchuk, Davids, Sakadjian, MacMahon, & Parrington, 2013) and distinguishing expertise (Wilson, Miles, Vine, & Vickers, 2013); thus, it would follow, that a longer QE that extends through release and tracks the object for the early portion of flight (task dependent) should be beneficial for performance. But when the trajectory of the object changed late in flight we demonstrated that tracking the object for longer predicted a large performance benefit. Relative to findings from studies that have used more traditional analyses (such as ANOVA; Panchuk & Vickers, 2006; 2009) and show whether a difference exists between groups, our use of logistic regression allowed us to quantify the predicted performance improvement observed by having a later occurring QE offset. Researchers should be encouraged to explore alternative methods of data analyses to continue to shed new light on how perceptual behaviour, such as QE, influence performance outcomes during object flight (e.g., Hopkins et al., 2009).

While results from this study demonstrate QE behaviour can effectively predict increases in shots saved, our use of deflection boards is a limitation which effects generalisability. In an actual ice hockey game, deflections would not be as predictable as in our current task because the puck is often unexpectedly re-directed by a player as it approaches. We would argue that an early onset, long duration QE would be beneficial for positioning the body initially. For example, in cricket, batsmen use postural cues arising from the kinematics of the bowler's actions to coordinate the initial step during the swing (Müller & Abernethy, 2006). Goaltenders could also use information from the shooter's actions to coordinate body movements in the direction of the pucks initial trajectory. It is uncertain whether the QE characteristics observed here would be beneficial for dealing with a more unpredictable deflection or whether the use of deflection boards creates a task constraint which causes significant changes in gaze behaviour. It is possible that other perceptual mechanisms such as peripheral vision may be important to supporting behaviour in a real-world context. Additional research involving another player deflecting the puck would be necessary to address these concerns however. Caution should also be used when using devices such as deflection boards for training purposes because they alter the information available for the goaltender to use for coordinating the save and are more predictable than deflections a goaltender would face in competition.

Practically, these findings demonstrate the importance of locating the optimal environmental location (i.e., the puck on a shooter's stick) at an optimal time (i.e., as early as 2000 ms prior to the shot being released) and maintaining the gaze on that location for an optimal duration (i.e., between 2033-2233 ms). While it is unlikely a goaltender will face conditions identical to this scenario in the real-world, these findings, along with those from previous work (Panchuk & Vickers, 2006; 2009), support the notion that training a goaltender to locate the puck as early as possible, and fixate/track as long as possible are beneficial. From a coaching standpoint, it may be beneficial to create practice scenarios that challenge a goaltender's ability to locate the puck by manipulating the number of players occluding their line-of-sight and forcing them to actively search for the most important source of perceptual information (i.e., the puck/stick region). This would promote goaltenders establishing an early QE onset and, by extension, longer QE durations. Given the importance of tracking, it would also be beneficial to come up with activities to improve sport-specific tracking ability. Promotion of a longer period of QE after puck release (i.e., late QE offset) could be achieved by painting a symbol on the puck (e.g., a number or letter) on the target object and having a goaltender verbally announce the symbol on the puck as it approaches (e.g., Adolphe, Vickers, & LaPlante, 1997).

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Tables

Table 1. Relationship between quiet eye (QE) measures and proportion (%) of shots resulting in a goal. The inference is shown for proportion of successful shots for the lower or upper quartile of the QE measure resulting in the lowest proportion of successful shots divided by that for the other three quartiles (a higher % of goals = poorer performance).

Measure	Quartile	Mean (range)[a]	Goals (%)	Goals ratio; 90%CI	Inference[b]
Absolute QE on	Lower	0 (0-0) ms	22	0.54; 0.32 to 0.86	Moderate ↓**
	Others	951 (67-2100) ms	41		
Relative QE on	Lower	0 (0-0) %	22	0.54; 0.32 to 0.86	Moderate ↓**
	Others	40 (3-88) %	41		
Absolute QE duration	Upper	2074 (2033-2233) ms	14	0.36; 0.18 to 0.67	Moderate ↓***
	Others	1262 (100-2000) ms	38		
Relative QE duration	Upper	89 (86-96) %	16	0.45; 0.23 to 0.82	Moderate ↓***
	Others	55 (4-86) %	36		
Absolute QE off	Upper	2132 (2100-2267) ms	11	0.29; 0.12 to 0.63	Large ↓***
	Others	2004 (1500-2067) ms	37		
Relative QE off	Upper	91 (89-96) %	9	0.25; 0.11 to 0.53	Large ↓****
	Others	85 (63-88) %	38		

90%CI: 90% confidence interval. All ratios were clear at the 99% level.
Likelihood that the true ratio is substantial: *possible, **likely, ***very likely, ****most likely.
[a] A value of 0 (ms or %) refers to the onset of the trial.
[b] Thresholds for evaluation of observed goals ratio: 0.84, small; 0.56, moderate; 0.32, large; 0.17, very large.

Figure Captions

Figure 1. Diagram of the experimental set-up.