Effect of the Look-Up Line on the Gaze, Head Orientation and Performance Of Elite Ice Hockey Players

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Abstract

A “look-up-line” (LUL) has been proposed for ice hockey, which is an orange 1 m (40 in) warning line (WL) painted on the ice at the base of the boards. The LUL purports to provide an early warning to players to keep their head up prior to, and as they are being checked. We determined if players looked-up more on a rink with the LUL compared to a traditional Control rink. Elite offensive (O) and defensive (D) players competed 1 vs 1, while wearing an eye tracker that recorded their quiet eye (QE) and fixation tracking (F-T) and an electro-goniometer that measured head angle. External cameras recorded skate duration during four skate phases: P1 preparation, P2 decision-making, P3 cut to boards, P4 contact. The QE was the final fixation prior to contact between O and D as they skated toward and across the WL during P3 and P4. Skate phase durations (%) did not differ by rink or rink by position. More QE and F-T occurred on the WL on the LUL rink than on the Control. The expected increase in head angle on the LUL rink did not occur during P3 or P4. Post-hoc results also showed O and D skated further from the boards on the LUL rink, suggesting the players preferred to control the puck on white ice, rather than the orange color of the LUL rink. More research is needed to determine if these results apply to the competitive setting.

Keywords: perception, vision, quiet eye, cognition, medicine, psychology

Introduction

Each season approximately 30% of youth ice hockey players sustain an injury, and 50% of these injuries occur in leagues that allow body checking (Malenfant, Goulet, Nadeau, Hamel, & Emery, 2012). Anecdotally, it is thought that getting pushed or checked into the boards with the position of the head and neck in flexion contributes to spinal cord injuries and concussion. A potential remedy is a 40 inch (1 m) wide orange "look-up line" (LUL) painted on the ice at the base of the boards (Smith, 2014). The goal of the LUL is to reduce injuries by providing both offensive (O) and defensive (D) players with a visual warning line (WL) to look-up and adjust the position of the head and body prior to being checked. Intuitively, the LUL appears to be a good idea, but no research exists showing the LUL causes players to look-up more leading to improvements in head orientation before and during contact. We therefore pursued one question: Does a LUL rink outfitted with an orange WL cause offensive (O) and defensive (D) players to look up more as they are being checked, compared to a traditional Control rink with a WL area of white ice? In the context of the current study, looking up was determined through an assessment of head flexion –extension angle in the vertical dimension, and a concurrent analysis of QE and fixations on the WL and other locations, before and as contact occurred.

Head Angle and Injury in Ice Hockey

There is a significant decrease in injuries when the head is raised allowing contact to occur with the shoulders /or chest and head up (Oktenoglu et al., 2001). Decreasing head angle reduces the normal cervical lordosis, which makes the head and neck more vulnerable to serious injury. This occurs in hockey when a player skates or slides on the ice without control or is pushed or checked from behind and hits the boards. Although dropping the head prior to contact increases the likelihood of head, neck and spinal injuries (Heck, Clarke, Peterson, Torg, & Weis, 2004), no attempt was made in the current investigation to determine if the orange WL increased or reduced injuries, as the degree of contact was mild to moderate and did not simulate highly competitive games where contact is often severe between the players and the boards.

Gaze During Motor Behavior

During dynamic movements humans exhibit fixations of longer duration on critical cues in the task environment (Henderson, 2003; Liversedge, 2011). Normally the eyes localize the target first, followed by the head due to it's greater inertia, and lastly by the body (Abrams, Meyer, & Kornblum, 1990; McCluskey & Cullen, 2007). Research in locomotion shows that two strides before an obstacle is reached there is a fixation on the obstacle, followed by fixations upward and forward into space that are used to ensure safe and effective navigation (Patla & Vickers, 1997). In walking studies where the probability of a collision is high, a rapid change in gaze occurs resulting in fixations that occur earlier and are of longer duration during potentially harmful collisions (Jovancevic-Misic & Hayhoe, 2009). We therefore expected both O and D to look forward on the ice to locations in advance of strides taken in that direction.

Analysis of the gaze forward into space was therefore critical in the current study, which required detection of fixations on a specific location (the WL) as the players cut toward the WL, and as contact occurred between O and D. The quiet eye (QE) is a perception-action variable defined as the final fixation or tracking gaze that is located on a specific location or object in the task space prior to the onset of a critical movement (Vickers, 1996; Vickers, 2007). Extensive research shows that an early onset (indicative of superior anticipation) and longer duration (indicative of an enhanced ability to focus) is a characteristic of higher levels of performance in a wide range of motor tasks (Mann, Williams, Ward, & Janelle, 2007; Rienhoff, Tirp, Strauss, Baker, & Schorer, 2016). Theoretically, the QE represents the time needed to organize the neural networks underlying the control of the movement (Mann, Coombes, Mousseau, & Janelle, 2011). The QE has previously been identified in ice hockey defensive play, and defined as the final fixation occurring prior to contact between O and D (Martell & Vickers, 2004). Prior to contact a combination of fixation and tracking (F-T) gaze were found located on the opponent, the puck, stick, boards, and net. Successful checks occurred when the D used a longer QE on the puck/stick and/or the opponent's body prior to contact. The QE in the current study occurred as the players cut toward and skated across the WL prior to contact occurring between O and D and the boards. If a higher percentage of QE were located on the WL on the LUL rink than, this would indicate the players were drawn to fixate the WL more prior to contact than when they performed on the Control rink. During P4, it was then critical to determine if O and D looked up more during contact, as claimed by the originators of the LUL. Head flexion-extension in the vertical dimension was therefore determined during P3 and P4.

From a theoretical perspective, shifts in gaze can be evoked using either bottom-up or top-down processing (Corbetta & Shulman, 2002). During top-down processing "the flow of information is from the 'higher' to 'lower' centers, conveying knowledge derived from previous experience rather than sensory stimulation" (p. 201). Since all the participants had practiced and played only on rinks with white ice, and none had experienced a rink with an orange WL, we expected they would be guided by top-down processing on the Control rink, due to extensive experience competing in this environment. However, when they competed on the LUL rink with the orange WL, they would be more susceptible to bottom-up processing, which involves a "single direction from sensory input, through perceptual analysis, towards motor output, without involving feedback information flowing backwards from 'higher' centers to 'lower' centers" (Corbetta & Shulman, 2002). Since the orange WL was a novel experience for the players, we expected more QE and F-T on the WL of the LUL rink during P3. It was then difficult to predict if O and D would look up more during P4 on the LUL rink than the Control, as predicted by Smith, due to the lack of research on head angle in natural environments (Anderst, Donaldson, Lee, & Kang, 2013). Suffice to say, if O and D experienced a greater increase in head angle during P4 on the LUL rink than on the Control rink, then this would provide support for the efficacy of the LUL in improving the position of the head and neck prior to and during contact.

Methods

Participants

Elite male university ice hockey players (N = 18; *M* age = 23.2 years, *SD* = 1.7) volunteered for the study and had played organized ice hockey for an average of 12.2 (s = 2.2) years. Athletes were assigned to pairs by the head coach in order to ensure they were evenly matched. Ethics approval was received and the athletes gave informed written consent prior to testing.

Equipment

O and D each wore a Mobile Eye 5 eye tracker (Applied Sciences Laboratories) and an electrogoniometer (SG150 Twin Axis, Biometrics) that was attached to the back of the head (inion) and upper spine (C7) using training wrap and medical tape. Skating movements were videotaped using two external cameras (Canon Vixia HF R42). Head angle data were collected at a rate of 2400 Hz, filtered at 10 Hz using a low pass 4^{th} order Butterworth filter and down sampled to 30 Hz, and synchronized to the F-T and motor data. Figure 1 shows an example trial and four synchronized O and D vision-in-action videos. The data collection rates of the eye trackers, electrogoniometers and skating movements were similar at 30 Hz (33.3 ms/frame).

Checking 1 vs 1 Drill

Figure 1 shows the 1 on 1 drill as performed on an Olympic ice hockey rink. A mini-rink was created (50.6m (116’) x 13.4m (44’) with a net and shooter tutor centered on the goal line. Each trial began with the O standing on the far blue line, the puck on the red line and the D on the near blue line. During P1 (Preparation), the O participant skated rapidly to the puck, while the D held his position until the puck was contacted. During P2 (Decision making), the O executed deceptive movements designed to gain an advantage, while the D anticipated and countered each move. During

P3 (Cut) the O cut rapidly toward the WL and boards, and the D angled him to the boards, closed the gap to zero, and prepared for contact. During P4 (Contact), contact occurred between O and D followed by the O attempting to drive skate by the D and get a shot on net, while the D tried to gain possession of the puck.

Protocol

Testing was carried out one week after the players returned from the national championships. Participants wore regulation hockey gear and a CSA certified ice hockey helmet (Bauer IMS 11.0) and face shield (CSA/CE) to ensure safety. After a 10-minute warm-up, O and D were fitted with the eye tracker and electrogoniometer and calibrated. The drill was explained, followed by two practice trials. A counterbalanced design was used with half of the player pairs being tested first on one rink and the other player pairs tested first on the other rink. Participants completed a total of 40 trials, 20 per rink, 10 on offense and 10 on defense, switching each trial. Before each trial began, catch trials were used to prevent the D player from anticipating which direction the O would skate. The O was covertly signaled to skate either right toward the boards, or left toward the bumper pads, a goal the D was unaware of. Total data collection took 2 hours.

Synchronizing Skate Phase, F-T and Head Angle Data

Synchronization began with the start commands, which were held constant and occurred simultaneously for O and D as follows: 1) “Look down at your skates”; 2) “Look up at the puck”, 3) “Ready, 4) “Go”. Each trial began with O and D standing on their respective blue lines. A head extension phase (0-466 ms) was used to ensure the calibration of the electrogoniometers and the eye trackers, in which the players were asked to look down at their skates and then up quickly at the puck located on the red line, thereby providing an upward spike in the head angle data that coincided with the fixation being located on the puck. Trial onset (500 ms) occurred during “Look at the puck” when O and D head extension reached the apex and fixation occurred on the puck on the red line.

Trial offset occurred when the D gained control of the puck, or the puck crossed the plane of the net or goal line.

Following data collection, the gaze and skate videos were synchronized using Adobe Premier, following precedents from previous ice hockey studies (Martell & Vickers, 2004; Panchuk & Vickers, 2006). The vision-in-action trials were coded frame-by-frame using the Quiet Eye Solutions (QES) software, which imposed a common time line (at 30 Hz) over the four videos shown in Figure 1. P1 onset coincided with trial onset, and offset occurred when the O contacted the puck on the red line. P2 onset was the first frame after puck contact and offset occurred one frame prior to the cut phase P3. P3 onset was the first change in skate direction of O and D toward the boards and offset one frame prior to contact, P4. P4 onset was the first frame showing O and D making physical contact and offset was similar to trial offset.

F-T onset, offset, duration and location were coded in order, relative to seven locations (puck/stick, opponent, near ice, far ice, WL, net, boards). Head angle data were averaged every 500 ms creating 17 time intervals from 0-8500 ms. Head angle and F-T were allocated to the skate phases using the phase onsets in Table 1: F-T and head angle between 500 ms - 3466 ms were allocated to P2; between 3500 to 4466 ms to P2; between 4500 to 6966 to P3; and between 7000 and trial offset to P4. QE and F-T locations were synchronized with the head angle time intervals using the F-T onsets and offsets. F-T onsets that did not coincide with a 500 ms interval were assigned to the nearest interval. To our knowledge this the first study to report head angle by F-T location of ice hockey players competing in a 1 vs 1 play. Although the electrogoniometers provided a measure of head angle, they were unable to identify the information being fixated during P3 and P4. Head angle by QE locations was therefore determined, revealing the orientation of the head relative to each QE location fixated prior to contact between O and D. Similar results were also determined for head-angle by all F-T locations during P3 and P4. Of particular importance was determining whether head angle relative to the WL during P3, led to the O and D looking up or down during P4.

Data Analysis

Catch trials (172) were removed in which the O skated toward the left bumper pads, where there was no WL (see Fig 1). Also removed were all trials (62) in which O and D failed to make contact, did not skate toward the WL and boards, or the O lost possession prior to contact, leaving 482 matched O and D trials. Due to breakage of the electrogoniometer cables, head angle data was available for 318 of the 482 trials (11 athletes).

Data were analyzed with SAS JMP 12 (SAS.com) using full-factorial repeated-measures linear mixed-effects ANOVA. Trial duration, phase, QE and F-T were measured in both absolute (ms) and relative time, or percentage (%) of total trial time and subjected to separate Rink (LUL, Control) x Position (O, D) ANOVAs. Head angle was analyzed using a Rink x Time Interval x Phase (P3, P4) ANOVA. Percentage of F-T was analyzed, by phase separately, using a Rink x F-T Location (puck/stick, opponent, near ice, far ice, WL, net, boards) ANOVA. Head angle by QE location, and head angle by F-T location were analyzed, separately, using a Rink x Location x Phase ANOVA. Since the focus of the study was on the effect of rink, only the main effects for rink and the interaction of rink by position are reported. Effect sizes were calculated using Cohen's *d*. Greenhouse-Geisser epsilon was used to control for violations of sphericity and the alpha level for significance was set at .05 with Bonferroni adjustment to control for Type 1 errors.

Results

Trial Duration and Skate Phase Onsets and Duration

Trial duration (ms) differed by rink, $F_{1,\,17} = 4.64$, p = 0.047, $d = 0.66$, LUL mean 7651.75 ms and Control mean 7351.56 ms (Table 1). Phase 1 to 4 onsets (%) and duration (%) did not differ by rink or rink by position. P3 duration (ms) was longer on the LUL rink, $F_{1,\,16.27} = 6.97$, p = 0.02, d = 0.42, and P4 onset (ms) occurred later, $F_{1,\,14.98} = 9.78$, $p < 0.007$, d = 0.68.

Number and Percentage of F-T

Number of F-T did not differ by rink, LUL rink = 7.85 F-T (± SEM .47), Control rink = 7.48 (± SEM .46), or the interaction of rink by position. Table 2 shows the percentage of F-T was very similar on all locations on the LUL and Control rinks, except for the WL. More F-T were found on the WL on the LUL rink, $F_{1,\,16.57} = 12.82$, p = 0.002, *d* = 1.69, LUL mean = 2.08 F-T (± SEM .27); Control rink mean = .39 (± SEM .26).

Quiet Eye Duration, Onset, Offset and Location

A total of 482 trials were analyzed, one QE per trial. QE duration (%, ms) did not differ by rink, or the interaction of rink by position, LUL mean = 14.9%, 1117.02 ms, Control = 15.4%, 1125.44 ms. When analyzed by location, QE duration on near-ice was longer on the LUL rink in relative time (%), $F_{1,\,21.17} = 8.25$, p = 0.05, *d* = *.65*, and absolute time (ms), $F_{1,\,18.63} = 8.25$, p = 0.04, *d = .49*. LUL = 790.70 ms, 11.39 %; Control = 4.12 %, 265.52 ms.

F-T Onset, Offset and Duration

A total of 1655 F-T were analyzed, including the QE. F-T onset (ms) occurred later on the LUL rink, $F_{1,\,15.67} = 4.14$, p = 0.05, *d* = *.47*, but this difference was not reflected in relative time (%), LUL mean = 6247.48 ms; Control mean = 6000.66 ms. F-T (ms) on the puck/stick occurred later on the LUL rink, $F_{1,\,15.67} = 5.21$, p = 0.04, d = .78, LUL mean = 6238.20; Control mean = 5950.61. No other differences were found.

Head Angle

A total of 317 trials were analyzed. Figure 2A shows that during P3, head angle declined across the time intervals, $F_{4,\,37.01} = 7.70$, $p < 0.0001$, *d = 2.85*, from a high of $16.35\,^{0}$ to a low of $8.7\,^{0}$. The interaction of rink by time interval was significant, $F_{4,\,34.33} = 2.84$, p = 0.04, *d = .55*, and ranged from 17.88^0 to 8.61^0 on the LUL rink, and $14.66\ ^0$ to 8.80 on the Control. During P4, there was no differences due to rink, or rink x position. Contrary to expectations, the participants did not look up more on the LUL rink during P3 or P4.

Head Angle x QE Location x Phase

Figure 2B presents the mean head angle by QE location during P3 and P4. During P3, the interaction of rink by QE location was significant, $F_{6, 37.34} = 4.36$, $p < 0.04$, $d = .62$. Contrast of means differed for far ice, $F_{1, 159.1} = 10.54$, $p < .001$. During P4, LUL head angle was lower on the Control rink, $F = 4.63$, $p = 0.04$, $d = .31$, LUL mean = $-3.85\ ^0$ and Control mean $=10.08\ ^0$.

Head Angle x FT Location x Phase

A total of 1214 F-T were analyzed, including the QE. Figure 2C presents the head angle to each F-T location during P3 and P4. The interaction of rink x F-T location was significant, $F_{6, 230.1} = 2.56$, $p = 0.02$, $d = .78$. Head angle declined relative to 6 of 7 locations from P3 to P4 on the LUL rink vs the Control. Contrast of means was significant for net, $F_{1, 97.55} = 9.00$, $p < .003$.

Post-hoc Distance Skated From the Boards

During the final days of data collection it appeared O and D skated further from the boards on the LUL rink. A post-hoc analysis of distance skated from the boards was carried which included four athletes. Two cameras were set up at the end of the ice (outside the glass) in a constant location on each rink, thereby ensuring the same view relative to the boards. Distance was measured in pixels and converted to cm from the skate of O and D nearest to the boards as they skated crossed the ringette line (Fig 1). A significant difference was found for rink, $F_{1, 74} = 8.06$, $p < 0.006$, $d = 3.96$, and position $F_{1, 74} = 14.80$, $p = 0.02$, $d = 5.20$. Distance skated from the boards was greater on the LUL rink, 246.6 cm (± SEM 19.26) than on the Control, 159.8 cm (± SEM 24.17). Distance from the boards averaged 165.6 cm (± SEM = 21.19) for the O, and 281.5 cm (± SEM 21.25) for the D.

Discussion

The purpose of the study was to determine if a LUL rink outfitted with an orange WL caused O and D players to look up more prior to be being checked, compared to a Control rink with a WL of white ice. In the current investigation it was critical that measures of head angle and F-T be determined concurrently as the O and D players skated toward the WL on the LUL and Control rinks during a cut (P3) phase, and during contact (P4) between O and D and the boards. The QE is one of the few gaze variables that, by definition, precisely couples a final F-T with a specific phase of a movement, thereby making it an ideal variable to be investigated in a study where it was necessary to determine not only if O and D players fixated the WL more on the LUL rink, but also if the QE and other F-T caused the O and D to look up more, as evidenced by a greater increase in head angle upward before and during contact.

The results confirmed the orange WL did attract significantly more F-T by both O and D on the LUL rink compared to the Control rink, but this did not lead to O and D looking up more during P3 (the cut phase) or P4 (contact). Indeed, our results show the opposite occurred, the LUL caused the players to look down more during both P3 and P4 on the LUL rink when compared to the Control rink. Our results thereby fail to support two main contentions of the originators of the LUL that the orange WL will “warn players to keep their heads up when approaching the boards”, and also “give players an opportunity to make proper bodily adjustments before hitting the boards” (Smith, 2014).

Five results are highlighted. First, a higher percentage of F-T occurred on the WL on the LUL rink during both P3 and P4 (see Table 2), confirming the WL did attract more of the F-T of both the O and D players. Second, QE duration was longer on near-ice during P3, when the players skated toward and through the WL area on the LUL rink, averaging 780 ms on the LUL rink, compared to 286 ms on the Control. F-T on near ice usually occurred when the athletes were having a problem controlling the puck on the stick. Third, head angle declined significantly more during P3 and P4 (Fig 2A) on the LUL rink, indicating both O and D looked down more than when they performed on the Control rink. Fourth, both head angle by QE location (Fig 2B), and head angle by F-T location (Fig 2C) declined more on the LUL rink from P3 to P4 on 6 of 7 locations, compared to the Control rink. Finally, trial duration (ms) was longer by 300 ms on the LUL rink, and the difference occurred primarily during P3, which was 153 ms longer compared to the Control rink, and contributed to a later onset of P4 (by 311 ms). Although these differences were not reflected in relative time, the presence of the orange WL appeared to slow the players down, a potentially “negative” consequence of the LUL, since prolonged head-down neck posture may increase the risk of concussion and spine injury.

Taken together, the results show the players were visually affected by the orange WL, in keeping with the nature of bottom-up processing. During bottom-up processing the athlete processes an immediate salient stimulus, whereas in top-down processing the athlete is guided by higher-level strategies developed during through years of training and competition. Usually performers are slowed down by bottom-up processing, which contributes to longer reaction times and slower movements (Itti & Koch, 2001). This occurs due to a psychological phenomenon known as inhibition of return (IOR). During IOR, participants normally exhibit a reluctance to fixate previously locations, preferring instead to fixate new locations on subsequent trials (Klein, 2000). When there is reduction in IOR, participants continually fixate the same location, leading to longer reaction times and delayed motor responses (Taylor & Klein, 2000). Our results can be interpreted to provide support for the IOR, since significantly more F-T occurred on the orange WL, and QE duration was longer on near ice during P3 when compared to the Control rink. These differences in gaze were accompanied by a slowing of the skating movements on the LUL rink, as indicated by a longer trial duration and P3 phase duration.

Overall, the darker color of the orange WL appeared to affect both the gaze and skating behaviours of O and D, an interpretation bolstered by one of the athletes who commented (after testing) that when he performed on rinks with dark team logos painted on the ice, he found it hard to keep his eye of the puck due to the lack of contrast between the black puck and dark logos. Similarly, when he performed on the LUL rink he felt he had to focus more on the puck when it was on the orange WL compared to the white WL of the Control rink. The human visual system possesses a number of bottom-up feature detectors (V1-V7) in the occipital cortex that are attuned to rapid changes in color, edges, lines and other features such as motion, depth and direction (Kolb & Whishaw, 2015). Processing of this information is powerful in terms of automatically generating changes in locomotion and higher cognitive processes (Astafiev, Stanley, Shulman, & Corbetta, 2004; Woolley et al., 2010). Looking down more on the LUL rink may have been needed due to greater difficultly seeing the puck against the orange color compared to white ice. This finding was also supported by the unexpected post-hoc result of both O and D skating further from the boards on the LUL rink than on the Control, creating a perceptually narrower rink that may have represented a comfort zone in terms of maintaining better control over the puck.

Limitations

The results may be specific to the 1 vs 1 play used, and may not continue throughout the season as players become accustomed to the LUL. The degree of body contact observed between the O and D was low to moderate. For this reason, we were unable to extrapolate the results to ice hockey competition, or predict if the LUL will prevent injuries. Technical difficulties with the electrogoniometer cables, and a low number of athletes tested in the post-hoc analysis of distance from the boards were also limitations.

Future Directions

Since the LUL has been approved by some ice hockey organizations, more research is needed to determine if the results found in the current study apply to the competitive setting. The presence of a LUL creates an opportunity for research and player education on the risk of injuries near the boards, as well as injury prevention strategies. Future epidemiological research using validated injury surveillance in youth ice hockey evaluating the influence of the LUL and programs such as "Heads Up, Don't Duck" injury and concussion prevention is warranted.

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Table 1. Mean trial duration (ms), and skate phase onsets and durations (ms, %, SEM) of the skate phases (P1 preparation, P2 decision, P3 cut, P4 contact) by rink (LUL, Control) and position (Offense, Defense). *P* values are provided for the main effect of rink, and the interaction of rink by position.

Table 2. Percentage of fixation-tracking by phase and rink to seven locations (puck/stick, opponent, near ice, far ice, warning line, net and boards).

Figure 1. The experimental set-up on an ice hockey rink, with the LUL rink on one end and Control rink on the other. The 1 vs 1 play occurred on a mini rink created in a corner of the ice. Inset is a “vision-in-action” trial showing four synchronized videos. The gaze (A) and skate movements (B) of the defensive player (white jersey) is shown synchronized with the gaze (C) and skating movements of the offensive player (D) in the dark jersey. Location of O and D gaze is indicated by the small circular cursors.

Figure 2. Figure 2A shows the mean QE head angle on the LUL and Control rinks across the time intervals of phases 3 and 4. Figures 2B and 2C shows the head angle of QE and F-T, respectively, by location during phases 3 and 4.