Effects of ice hockey facial protectors on the response time and kinematics in goal-directed tasks

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Abstract: Ice hockey facial protectors are essential to prevent eye (and, in some cases, dental) injuries but must also not encumber vision and, in turn, players' performance. The purpose of this study was to investigate the effects of three different facial protection conditions on temporal and kinematic parameters in a goal-directed pointing task: helmet (control), visor, and cage. Start and end target switches captured temporal estimates (reaction time (RT), movement time, (MT), and response time (RT + MT)), while a 13-light target array and 6-camera Vicon Mx system were used to collect upper-body kinematics data (head and thorax orientation, shoulder and elbow joint angles). Subjects recruited were 16 male and 12 female varsity ice hockey players ($n = 28$). Results demonstrated that, although kinematics remained largely unaffected, throughout the target array RT + MT increased significantly with the cage (23 ms) as well as delayed initiation of head rotation for both the visor (14 ms) and the cage (18 ms). These differences may well represent a functional disadvantage to a player's performance given the dynamic open environment where multiple players contest for puck possession. It must be stressed that facial protectors still provide an effective form of protection and thus should still be worn at all levels of play. In summary, further research is warranted to achieve both optimal performance and safety.

Keywords: helmet, visor, cage, facial protection, response time, reaction time, movement time, kinematics

1 INTRODUCTION

Ice hockey is a fast-paced sport involving numerous intentional as well as unpredicted collisions; hence, participation involves an inherent risk of injury. To preclude and/or decrease the severity of physical injury, various protective devices are worn by players. For instance, protection of the eyes from stray puck and stick impacts is paramount. Security may be provided by facial protectors (or faceguards) suspended from the player's helmet and typically consisting of translucent synthetic polymer visors or wire lattice cages. Protection against facial injuries through the use of visors (full and half-shield) and cages has been well documented [**1–5**]. Whether facial protectors may also reduce concussion prevalence and frequency has been suggested but not conclusively observed [**5–7**].

However, given the game's heavy reliance on vision for environmental cues of location and movement of the puck as well as players, any impairment in the field of vision has the potential to lower one's level of play. The perception within the hockey community that facial protectors obstruct vision has been anecdotally reported [**8–10**] and may explain why players opt voluntarily not to use facial protectors where league rules permit.

Prior research from various sport contexts indicates that these concerns may have some merit. For example, Ing *et al.* [**11**] examined the effects of sport visors and goggles on visual detection and observed a substantially reduced reaction time in peripheral vision (greater than 60° from visual fixation), particularly with the sample visors studied. To demonstrate the consequence of a specific factor (e.g. player experience, learning effect, or eye wear), vision–task experimental designs commonly use reaction time or

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response temporal measures [12–14]. This metric is relevant to ice hockey tasks, as a slight latency in the response time of a player could affect both performance and safety.

In addition to time estimates, visual perturbation in goal-directed pointing movements has been shown to alter body segment sequence and kinematics [15–20]. Depending on the nature of the task, certain coordinated patterns occur. For instance, a coupling between the head and arm [21, 22] as well as between the shoulder and elbow [23–27] may exist, or a specific chronological sequence of head and then arm movement [28]. Hence, tracking body movement patterns is a pertinent indicator of performance and may be altered owing to different visual conditions.

To date, no studies have examined specifically the effects of ice hockey cages and visors on temporal and kinematic parameters in goal-directed tasks. Thus, the purpose of the study was to investigate the effects of three different facial protection conditions on reaction time (RT), movement time (MT) (and the summed response time (RT + MT)), and upper-body kinematics in a goal-directed pointing task. Three facial protection conditions were evaluated: helmet (control), helmet with visor (visor), and helmet with cage (cage) (Fig. 1).

2 METHODS

2.1 Subjects

Healthy subjects from the male and female intercollegiate ice hockey teams ($n = 28$) were recruited to participate voluntarily in the project. The age range of subjects was 18–25 years old, a population sample consisting of 16 males and 12 females. 15 of the subjects were accustomed to playing with visors and 13 were accustomed to playing with cages. 25 subjects were right handed and 3 were left handed. Subjects had no previous history of neuromuscular disorders, balance disorders, or sensory loss.

2.2 Experimental set-up and protocol

A subject stood in front of 13 light-emitting diode (LED) light targets, arranged at equal intervals along a 180° horizontal arc array positioned at shoulder height and a distance of 1.3 arm lengths away (Fig. 2). Three test conditions were examined for players wearing a helmet (constant):

(a) no facial guard (control) (Fig. 1(a));
(b) a visor (Fig. 1(b));
(c) a cage (Fig. 1(c)).

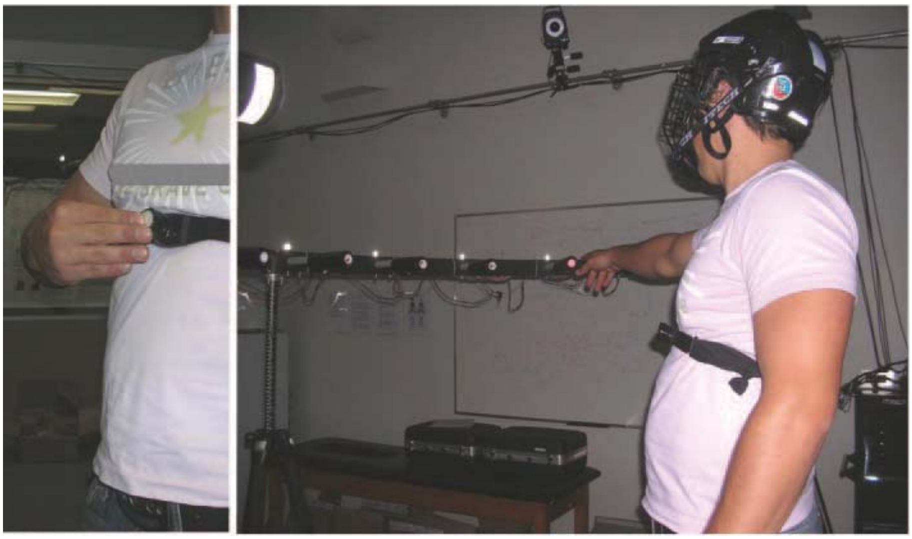
Passive reflective markers were strategically placed on the subjects' body in accordance with the Vicon full body plug-in-gait model (Vicon, Los Angeles, USA).

The subjects began with the index finger of their preferred hand pressing a chest trigger situated at the height of each subject's xiphoid process just in front of their torso's midline. Subjects were instructed to focus on a passive reflective marker placed on the frame of the array above the light diode at the centre of their visual field and, upon random illumination of lights in the array, to remove their hand from the chest trigger and to press the target as quickly as possible (Fig. 2). The light diode, upon the readiness of the subject, was activated at a random time between 500 and 2000 ms after an auditory cue. The experiment set-up is illustrated in Fig. 3.

As the study used a repeated-measures design, all subjects took part in all three conditions, preceded by 20 practice trials in order to allow them to become accustomed to the light array and pointing task. Furthermore, the order of conditions was randomized for each subject, in order to eliminate practice effects. Each subject underwent 65 trials per facial protection condition, for a total 195 trials throughout the course of the testing ($13\,\text{lights} \times 5\,\text{trials} \times 3\,\text{conditions} = 195$ trials).

(a) (b) (c)

Fig. 1 (a) Control; (b) visor; (c) cage



(a) (b)

Fig. 2 (a) The subject begins with their index finger pressing the chest trigger; (b) upon illumination of the light target the subject removes their hand from the chest trigger and presses the light trigger

2.3 Data acquisition

A six-camera Vicon Mx system (Vicon, Los Angeles, USA) was used to collect kinematic data of the upper body. The infrared cameras were strategically placed in fixed locations around the experimental set-up in order to allow for the subjects' movement to be fully captured. The camera set-up also allowed all markers to be seen by a minimum of two cameras in each trial in order to calculate their three-dimensional (3D) coordinates. The sampling rate of the Vicon Mx system was set at 200 Hz in order to retain adequate camera resolution.

An input–output data acquisition board and software program (LabVIEW™ 8, National Instruments™) were used to operate the light array, to synchronize it with the Vicon Mx system, and to capture response time data. The software allowed for the randomization of both the light diode illuminated and the time between the warning signal and the illumination of the light diode. Light array temporal data were collected at 1000 Hz. The following temporal measures were calculated:

(a) RT: the time between the illumination of the light diode and the subject removing their hand from the chest trigger;
(b) MT: the time between the subject removing their hand from the chest trigger and depressing the light diode target;
(c) RT + MT: the sum of RT and MT.

In order for the LabVIEW system to determine that a certain event has taken place, a 5 V spike occurred at the onset of each of the three events:

(a) illumination of the light diode;
(b) subject removing their hand from the chest trigger;
(c) subject depressing the light diode target.

2.4 Data processing

Reconstructed 3D coordinates of the reflective markers were identified and tracked during each trial using a combination of Vicon Nexus 1.3.106 and Vicon iQ 2.5 software (Vicon, released 2006). Prior to the data processing, individual subject models were calibrated to label each marker for all trials (where-in the numerous markers recorded are specifically identified or labelled). Odd-numbered light trials were processed for the kinematic variables (lights positioned 0°, 30°, 60°, 90°, 120°, 150°, and 180° in the light array).

Marker switching or the misidentification of two adjacent markers by the trajectory labeller of the software was manually corrected at the point of occurrence. When a marker drops out of the view of at least two cameras, the 3D reconstruction is not possible and this may create a gap in the marker trajectory. In this situation, if the gap is less than 50 frames long, the marker position was interpolated using a cubic spline. If the gap was greater than 50 frames long, the marker position was calculated and filled using Vicon iQ's 'virtual points' function.

After all the markers were labelled for each trial, the data was filtered using an 8 Hz low-pass Butterworth filter. The cut-off point was selected through examination of Fourier analysis of the movement data, which indicated that over 95 per cent of the power spectral density was below 8 Hz. Following the filtering routine, trials were run through Vicon Nexus' dynamic gait function, a process which allowed for the software to calculate and display local rotational displacement of the different body segments. Anatomical referencing was used to calculate all joint angles. Velocities and accelerations of the marker coordinates were obtained when needed using a

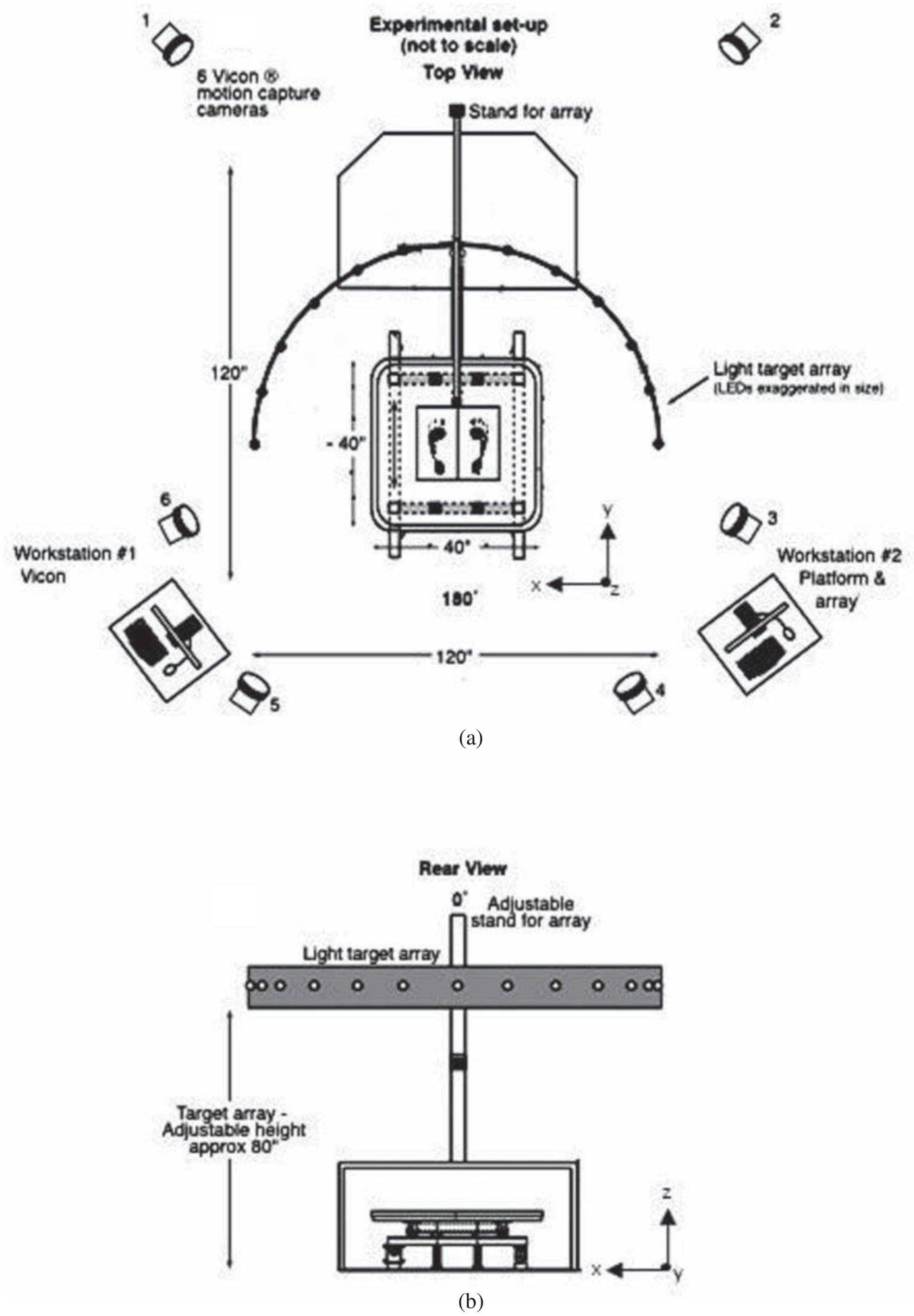


Fig. 3 (a) Top view of the experimental set-up (180° array of the LEDs in a clockwise direction from left to right; (b) rear view of the light target array and platform

finite difference algorithm implemented in MATLAB 7.5 (MathWorks software®, released 2007).

When dealing with temporal data (RT, MT, and RT + MT) from the three left-handed subjects who volunteered to participate in the study, the light numbers were reversed in order to match up the contralateral data with the right-handed subjects' contralateral data and vice versa. Left-handers were omitted for kinematic data processing and analysis.

2.5 Data analysis

The independent variables include the three facial protection conditions as well as each of the 13 light diode positions. The dependent variables were subdivided into two broad categories of temporal and kinematic data. As noted earlier, temporal data consisted of RT, MT, and RT + MT measures. Upper-body kinematics included angles of the head and thorax segments and effecter shoulder and elbow joints. To permit comparison between test conditions, discrete angular displacement and velocity measures were identified as follows:

(a) trigger angle (TA), coinciding with finger release at the chest trigger;
(b) final angle (FA), coinciding with contact of the light target;
(c) peak angle (PA), the maximum joint during the task.

Further discrete parameters were calculated:

(d) peak angular velocity (PV);
(e) time index (PA_{indx}) of peak angular displacement and time index (PV_{indx}) of peak angular velocity;
(f) difference between the (PV_{diff}) PV of the shoulder and the PV of the elbow;
(g) difference (RT_{diff}) between RT and the start time of head movement.

The latter parameters are mean estimates of upper-limb coordination, as indicated by the chronological sequencing and the magnitude of the differences between the PVs of adjacent segments and joints.

The RT + MT data analysis included all 28 subjects. For the kinematic data analysis the three left-handed subjects were omitted and three further subjects were omitted owing to technical difficulties with the Vicon system at the time of data collection. However, these omissions still left a robust total of 22 subjects included in the kinematic data analysis. For the head and thorax, only the transverse plane (z-axis, yaw) was taken into account (as these were the largest and most consistent movements observed). For the shoulder, movements about all three functional axes were measured given the substantial travel occurring as the arm lifted upward and transversely to each target. Only the x-axis (flexion–extension) was taken into account for the elbow.

Once the data were inspected for outliers of two standard deviations above or below the mean, SPSS 15.0 (SPSS Inc., released 2006) was used for statistical analysis. Dependent measures (RT + MT and kinematic data) were analysed using a repeated-measures analysis of variance (ANOVA) with two factors (light position, 13; facial coverage conditions, control, cage, or visor); $\alpha = 0.05$. The significant main effects were explored using pairwise comparisons (with a Bonferroni correction) and Bonferroni post-hoc analysis.

3 RESULTS

In this section, each light will be denoted by its angular position on the light array in the counter-clockwise direction from right to left. As an example, the light to a subject's far left will be denoted as 0°. The other 12 lights will follow in order from 15° to 180° at 15° intervals. The following text reports on the RT + MT and kinematic values.

3.1 Response time data

The temporal data (including RT, MT, and RT + MT) will be addressed in this section of the results. Table 1 displays the grand mean of each dependent variable in each condition together with the corresponding p value. As can be noted, significant differences were present between the RT + MT values ($p = 0.019$), but not between the RT or the MT values. Pairwise comparisons indicated that the RT + MT of the cage condition was significantly longer than that of the control condition ($p < 0.05$). In addition, a rank order in RT + MT latency was observed between the control, visor, and cage conditions, with means of 842.82 ms, 855.23 ms, and 866.15 ms respectively (Fig. 4). Similar ordering was observed for most light positions (Fig. 5). Post-hoc analysis revealed no further differences. Repeated-measures analysis showed no significant differences for individual measures of RT or MT.

3.2 Kinematic data

Kinematic variables of the head in the transverse plane were examined. Table 2 displays the results of the statistical analysis of these variables.

Repeated-measures ANOVA found significant differences in TA ($p = 0.014$). Pairwise comparisons showed a significant difference between the visor and control conditions of 1.43° (9.13° versus 10.56°, $p = 0.032$). While the difference between the means of the control and cage conditions was greater than that between the control and visor conditions (9.05° versus 10.56°), the pairwise comparison revealed that, as the p value approached 0.05, there was no significance ($p = 0.055$). When delving further into the TA variable differences with a post-hoc analysis, inspection showed that differences between the control and visor conditions existed specifically at the 0° light position (14.69° versus 11.62°, $p = 0.031$).

Table 1 Mean RT, mean MT, and mean RT + MT (with standard error) p-values for the main effects

Dependent variable	Mean (standard error) for the following conditions: Control	Visor	Cage	p
RT (ms)	412.69 (8.97)	411.90 (10.07)	421.86 (11.63)	0.085
MT (ms)	425.82 (16.40)	435.96 (17.97)	434.52 (15.74)	0.153
RT + MT (ms)	842.82 (18.22)	855.23 (19.45)	866.15 (18.06)	0.019

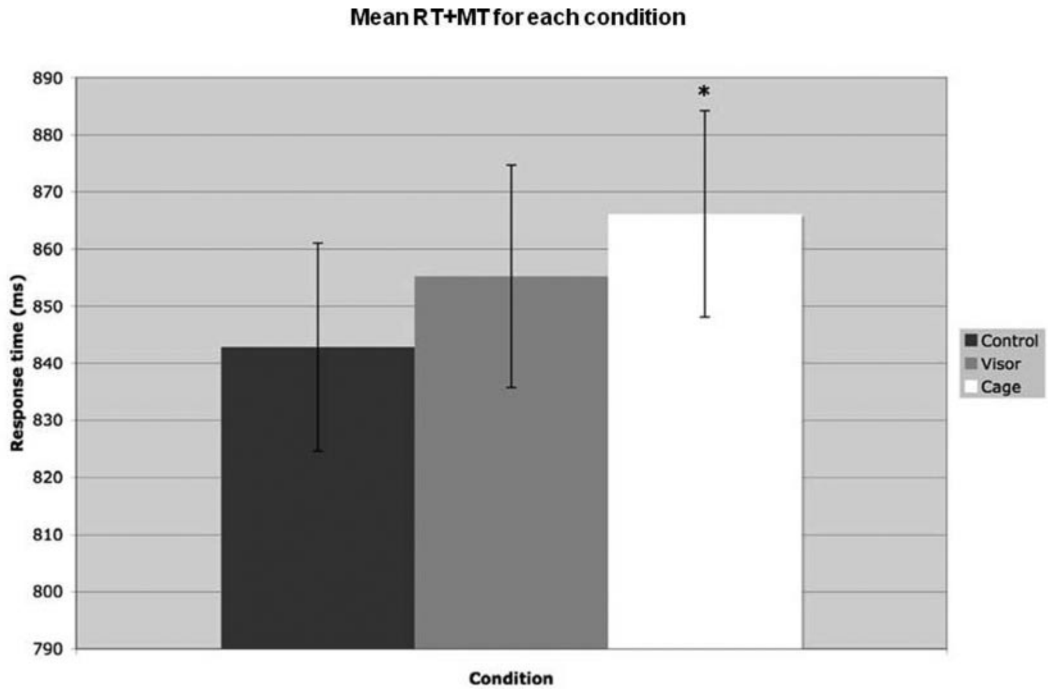


Fig. 4 Response times (mean RT + MT and standard error) for each condition (*, significant differences from the control condition)

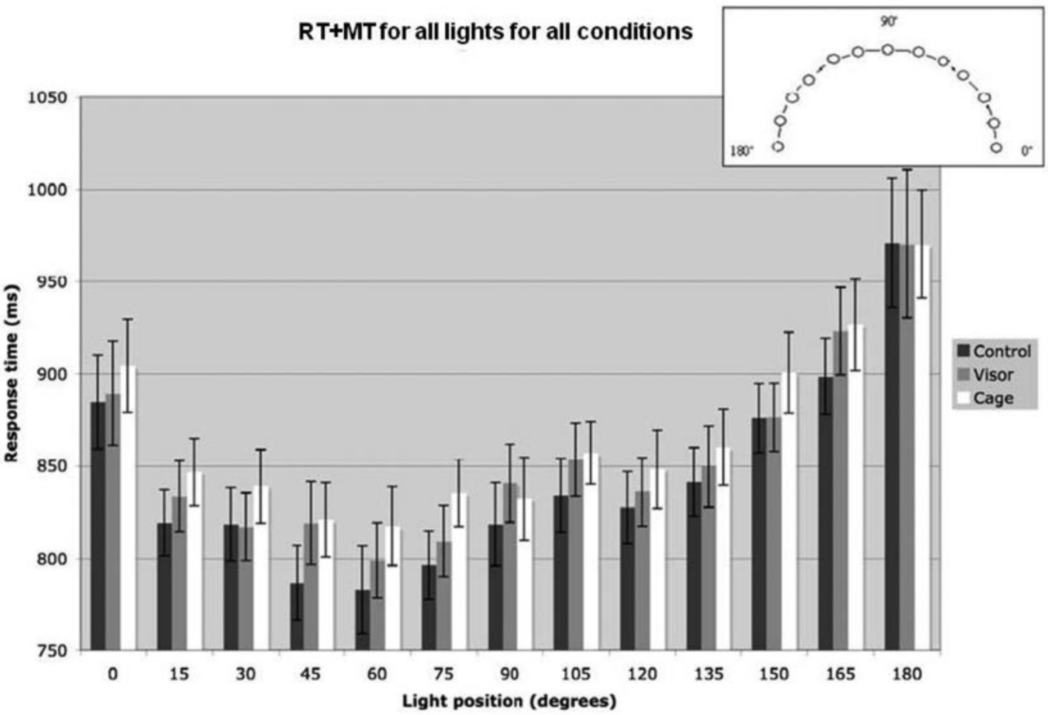


Fig. 5 Response time (mean RT + MT and standard error) at each light for each condition

The 1.43° main effect and 3.07° post-hoc discrepancies found, while statistically different, are probably due to small variance values and probably do not amount to functional differences in movement.

The PV_{indx} variable also yielded significant results ($p = 0.000$). As shown in Fig. 6, pairwise comparisons showed that this significance existed both between the control and cage conditions (89.71 ms versus 107.84 ms, $p = 0.001$) as well as between control and visor conditions (89.71 ms versus 103.69 ms, $p = 0.003$). Bonferroni post-hoc analysis revealed further differences between the control and visor when subjects pointed to the light positioned at 120° (58.23 ms versus 93.33 ms, $p = 0.040$) (Fig. 7).

As can be noted in Table 2, repeated-measures ANOVA revealed no other significant differences between any conditions for any other dependent variables when examining the motion of the head about the z-axis.

Statistical analysis of the kinematic variables of the thorax, shoulder, elbow, head–arm chronology, and shoulder–elbow chronology revealed no significant differences across conditions ($p > 0.05$).

Table 2 Means (standard errors) of all kinematic dependent variables for the head in the transverse plane

Dependent variable	Mean (standard error) for the following conditions: Control	Visor	Cage	p
TA (deg)	10.56 (1.13)	9.13 (1.03)	9.05 (1.07)	0.014
FA (deg)	39.55 (0.92)	39.77 (0.79)	39.82 (0.82)	0.754
PA (deg)	40.72 (0.88)	40.98 (0.78)	41.00 (0.85)	0.672
PV (deg/s)	177.35 (7.67)	171.19 (6.58)	170.96 (6.53)	0.081
PA_{indx} (ms)	808.16 (18.99)	812.41 (20.86)	819.19 (21.39)	0.660
PV_{indx} (ms)	89.71 (9.56)	103.69 (8.84)	107.84 (9.74)	0.000
RT_{diff} (ms)	151.36 (8.31)	148.28 (9.09)	148.97 (8.59)	0.733

4 DISCUSSION

While facial protectors are essential to prevent eye injuries (as well as dental injuries for full face shields), they must not encumber vision and, in turn, performance. In this study, performance was assessed in terms of response time and body kinematics in a goal-directed pointing task. While wearing the cage, the trend for greater RT and MT was observed (i.e. 9.17 ms and 8.70 ms longer; $p = 0.085$ and 0.153 respectively). Significant differences were observed with respect to overall RT + MT ($p = 0.019$) between the control and cage conditions, with the latter 23 ms longer on average for all targets than the former. In addition, a rank order of mean RT + MT values was observed between the three conditions (control < visor < cage; 843 ms < 855 ms < 866 ms respectively). Arguably, the 23 ms difference between the control and cage mean RT + MT values represents a functional significant effect. For instance, in the study by Ando *et al.* [**12**], which measured the time between a stimulus on a computer screen and the depression of the space bar on a keyboard, a maximum mean discrepancy of 30 ms was found between the peripheral visual RT + MT (stimulus in the periphery of the field of vision) and the central visual RT + MT (stimulus at the centre of the field of vision). Thus, the 23 ms difference found in the current study is similar in magnitude to the contrasting conditions in other studies.

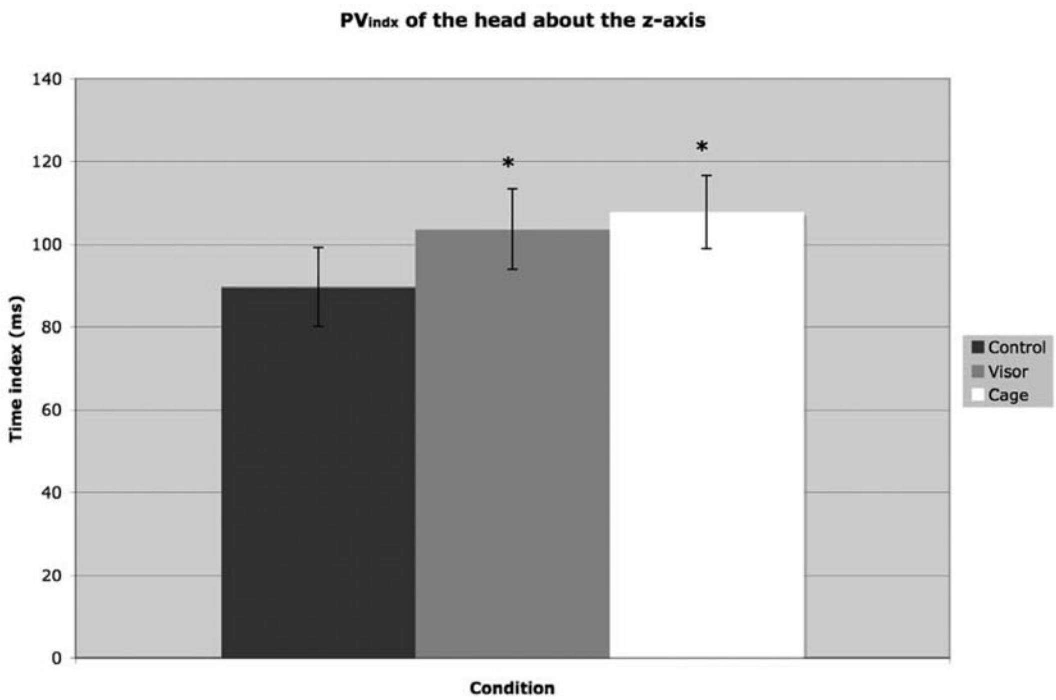


Fig. 6 Mean (and standard error) of time indices for the peak velocity of the head about the z-axis for all conditions (*, significant differences from the control condition)

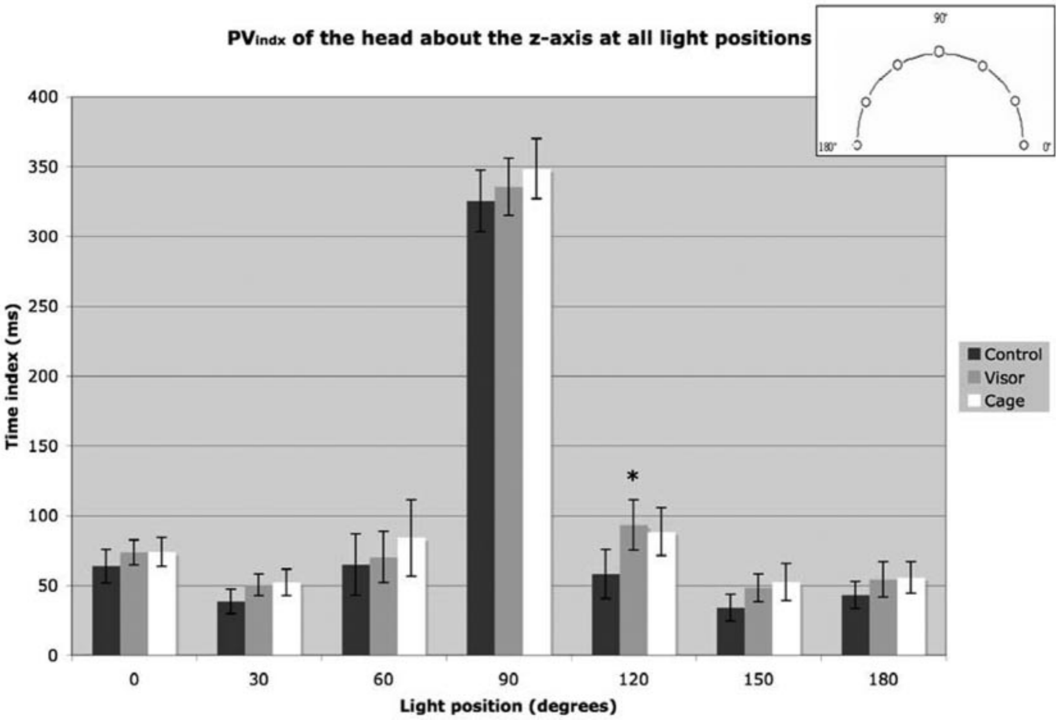


Fig. 7 Mean (and standard error) of time indices for the peak velocity of the head about the z-axis at all light positions for each condition (*, differences from the control condition)

With respect to RT, the observed range of mean values fall within those noted in the literature, ranging from 200 ms to 500 ms [**12, 15**, **20**, **29**]. For instance, a study that in part examined pointing by hand with an unrestricted visual feedback towards a randomly illuminated target [**15**] demonstrated a mean RTs range from 332 ms to 402 ms. Thus, the magnitude of RTs from the present study are comparable with those in previous reports.

With respect to specific light targets, the present study's mean RT values ranged from 381 ms (visor, 90° light position; central field of vision) and 466 ms (cage, 180° light position; peripheral field of vision). These differences between central and peripheral visual RTs are in agreement with previous literature [**12**, **30**]. Variation in visual stimuli perceived by different areas of the eye presumably produce different RTs, with the fastest RT coming when a stimulus is picked up by the cones (looking straight ahead) and slower RT existing when the stimulus is seen by rods (around the edge of the eye) [**30**]. Across targets, similar rank order trends and magnitude differences between conditions were observed. Hence, visors and cages affected the RT similarly across the visual field.

In a fast-paced sport such as ice hockey, the 23 ms RT + MT discrepancy between the control and cage conditions may represent the difference between failure and success in various performance measures [**31**]. To appreciate the implications of this seemingly short time frame, the period from presentation of a visual stimulus to the beginning of a motor response can be as low as 125 ms [**32**], of which 23 ms makes up a notable portion. Consequently, the prolonged RT + MT could negatively affect the outcome of a battle for the puck, anticipating a collision, blocking a shot, or reading player movements. Hence, future design of facial protectors needs to minimize visual obstacles due to the wire placement, configuration, width, colour, etc., to minimize RT + MT delays.

With regards to body movement, few kinematic differences were observed. Movement of the thorax, shoulder, and elbow were unperturbed. For the most part, wearing of the visor or cage did not affect gross motor pattern in the reach and point task, as evident from the stable joint kinematics from trigger release (TA) to final end point (FA). Significant differences were discovered for the head about the z-axis (yaw, or side-to-side orientation). In particular, differences in PV_{indx} of the head existed between both the control and visor (14 ms; $p < 0.003$) and the control and cage conditions (18 ms; $p = 0.001$). Presumably, this delay in head movement with the protectors in place corresponded to above-noted greater response times.

The chronological sequences of head, thorax, shoulder, and elbow movements were not affected by the visor or cage. Head movement initiation did in fact precede hand movement initiation (RT_{diff}), similar to reports by Suzuki *et al.* [**28**]. While it seems that the perturbed vision due to the cage did alter

RT + MT, perhaps the use of visual allocentric cues, defined as visual cues in a subject's surrounding environment, were used to localize the target. This strategy has been previously proposed in a review article by Desmurget *et al.* [**20**] and could allow for kinematics of this goal-directed pointing motion to be left largely unaffected; i.e. visual cues around the testing area may have been utilized to a greater extent to compensate for decreased visual clarity and thus allowed the gross movement pattern to remain intact.

In summary, analysis of kinematics between conditions revealed few significant differences, with the exception of an increased PV_{indx} latency of the head about the z-axis for both the visor and the cage conditions, with means corresponding to the rank order observed in mean RT (control < visor < cage). Examination of kinematic variables confirmed that, while a latency of movement was observed, movement patterns remained largely intact throughout all conditions.

This study was performed in the laboratory in order to control the environment as much as possible, therefore enabling differences in RT + MT to be attributed to the change in facial protection condition. While this allowed for excellent internal validity, there are limitations to the extent of external validity that can be taken from the results. How much these findings may be generalized to various on-ice conditions, such as shooting accuracy, defensive measures, and even competitive game situations remains to be determined. A second point of note is that there were a number of other possible optical features associated with visors that were not explored. These factors include fogging, ice shaving condensation, scratches, glare, and visual distortion, the latter of which may be increased when looking through the bottom of the visor. Hence, results of this study cannot be extrapolated to explain all areas of potential visual perturbation pertaining to visors.

From the above findings, further investigations are warranted. First, the extent of inter-subject differences in RT + MT and body movement patterns was not inspected in this study, although differences in eye saccade behaviour between individuals may modulate the head motion measured. Hence, this issue needs to be addressed to customize the protector type in the best way for the end user. Second, it would be beneficial to include a vertical dimension to the array target to study the effects of both the wire lattice of the cage as well as the different areas of the visor (i.e. bottom rim) during tasks requiring multiple planes of vision. Additionally, varied depths of targets would augment the task's challenge. Finally, on-ice conditions examining shooting accuracy, puck handling, defensive measures, and even competitive game situations need to be examined. For instance, using targets set up in an ice hockey net, a shooting accuracy study could be performed with different facial protectors in order to analyse the effects that they have on shooting kinematics, accuracy, and precision. Moreover, puck handling could be evaluated using cone drills and defensive measures examined by following a stimulus around the ice surface and reacting to its movements. The expansion to a game situation could include player anticipation and preparation for oncoming body contact.

5 CONCLUSION

While the kinematics of the upper body during the goal-directed pointing task remained largely unaffected, there was an increased RT + MT while wearing a cage covering and, to a lesser extent, with visors. Presumably these effects are indicative of a decrease in vision while wearing the cage and visor. A slight increase in response latency at the elite level of ice hockey has the potential to limit a participant's ability to react to a change in their surrounding environment, such as an oncoming collision or puck movement. It must be stressed that facial protectors still provide an effective form of protection for the eyes (and mouth for the full shield) and thus should still be worn at all levels of play. Further efforts to optimize the design of ice hockey facial protectors must continue in order to achieve the most effective model pertaining to both safety and performance.

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