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EFFECTS OF ICE HOCKEY FACIAL PROTECTORS ON RESPONSE TIME AND KINEMATICS

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ABSTRACT

Ice hockey facial protectors are essential to prevent eye and 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 response time (RsT) and kinematics in a goal directed pointing task: helmet (control), visor, and cage. A 13 light target array and six-camera Vicon Mx system were used to collect response time and kinematic data. Subjects recruited were 16 male and 12 female varsity ice hockey players (n=28). Results demonstrated that although kinematics remained largely unaffected, throughout the visual field test RsT increased significantly with the cage (23 ms) as well as delayed head movement for both the visor (14 ms) and 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. In summary, further research is warranted to achieve both optimal performance and safety.

ABRÉGÉ

Les protecteurs faciaux au hockey sur glace sont essentiels pour protéger des blessures potentielles aux yeux et à la dentition, par contre l'utilisation de ces protecteurs peut aussi encombrer la vision et de ce fait peut-être aussi la performance des joueurs. L'objectif de cette étude était d'évaluer l'effet de trois types de protecteurs faciaux; casque (contrôle), cage et visière, sur le temps de réponse (RsT) et sur la cinématique dans une de pointage orientée. Un appareillage de 13 cibles lumineuses ainsi qu'un système de 6 caméras infra-rouges ont été utilisés pour enregistrer les temps de réponse et la cinématique. 28 joueurs de hockey de niveau universitaire (16 hommes et 12 femmes) ont été recrutés pour participer à l'étude. Les résultats ont démontrés que malgré que la cinématique est restée sensiblement inchangé, les temps de réponse ont augmentés de façon significative avec la cage, de plus les mouvements de la tête pour les conditions avec la visière et la cage ont présentés un délai de (14 ms et 18ms respectivement) comparativement à la condition contrôle. Ces différences pourrait représenter un désavantage fonctionnel sur la performance d'un joueur si on considère un environnement dynamique ou plusieurs joueurs lutte pour la rondelle. Par contre, d'autres recherches sont nécessaires pour optimiser la performance et la sécurité des protecteurs faciaux.

1.0 INTRODUCTION

1.1 Objectives

Facial protectors are essential to prevent eye injury but must also not encumber vision and, in turn, players' performance. Hence, to examine the latter, this study investigated the effect of three ice hockey facial protection conditions during goal directed tasks towards visual cues. Both response time and human movement kinematic data were evaluated to identify differences, if present, between conditions.

1.2 Context

With the intent of providing pertinent background information the following text describes relevant studies that have addressed facial protection in ice hockey and their role in injury prevention. Subsequently, a review will be presented of common scientific methods to assess reaction, response and movement times as well as kinematics during goal directed tasks.

1.3 History of head and facial protection

Throughout the history of the sport of ice hockey, the equipment (i.e. skates, sticks, protective padding, helmets, etc.) has evolved continuously, with players and organizations vying for a competitive edge as well as to offer increased protection from the inherent injury risk due to the contact nature of the sport. With regards to the latter, this has been met with some success. For instance, after 1979, when a National Hockey

League (NHL) rule was implemented requiring players coming into the league to wear helmets, a large decrease was seen in the occurrence of head injuries (Azuelos et al., 2004). However, as with many interventions, unanticipated consequences arise. Following the prior example after the initial decrease in head injuries, from 1997-1998 to 2001-2002, the reported concussion rate tripled from the previous decade (Wenneberg & Tator, 2003). This statistic may be attributed in part to the increased size and strength of professional hockey players over the time period (Montgomery, 2006), yet arguably the rule change may have increased players' sense of invulnerability, in turn, promoting riskier behaviour such as cross checking and high sticking. In summary, the effectiveness of adopted equipment is a function of many engineering and social factors.

More recently, there has been movement by various community and athletic organizations to improve protection of the eyes and teeth. Yet, while mandatory at some lower levels of play, such as youth hockey, cages are rarely ever used in professional play. For example, data from the 2001-2002 season indicated that 77% of players in the league did not wear visors on a regular basis (Stevens et al., 2006). Arguably, players' resistance to adopting visors or cage over the face is, in part, due to a perceived decrease in vision clarity.

1.4 Added safety of facial protection

Despite the low compliance for use in professional leagues, the added protection given to hockey players through the use of visors, cages and face-shields has been well documented. Much of this literature surrounds the incidence of non-concussion head injuries. A study investigating injuries in a Swedish Elite League hockey team

(Lorentzon et al., 1988) over a three-year period noted that 42% of the team's players wore a face visor during games and practice. While players wearing a visor had 13.8% of all facial lacerations, those who chose not to wear a visor had 86.2% of this injury type. In addition to these findings, it was observed that roughly half of these injuries in players without facial protection would most likely have been prevented if the player had been wearing a visor. In contrast, Rampton et al. (1997) reported that, while full facial protection (i.e. cages) reduced the chances of upper facial injury, the risk of this injury was the same while wearing a half visor as wearing no facial protection at all. One study examining the effects of visors on head and facial injury in National Hockey League players during the 2001-2002 season (Stevens et al., 2006) found that visors minimized eye injuries and other non-concussion head injuries. In addition, a comparison of facial protection and the incidence of injuries in Junior A hockey players determined that players wearing no facial protection were injured at a rate greater than twice that of players wearing partial protection and nearly seven time that of players wearing full facial protection (Stuart et al., 2002). In yet another example of the increased safety brought on by the use of facial protectors, Pashby (1977) attained reports from Peel Memorial Hospital (Brampton, Ontario), that was in a unique situation to monitor hockey injuries directed from the Brampton Minor Hockey League (that enforced mandatory facial protection for its 2200 players) as well as other leagues. Between September 15, 1976 and January 5, 1977, 138 hockey injuries were treated at the Peel Memorial Hospital, including 65 facial injuries. Of the players who attained facial injuries, none were among the 2200 masked players in the Brampton Minor Hockey League. In another article by Pashby (1989), it was stated that because minor hockey players in Canada were now required to wear Canadian Standards Association^{TM} certified face protectors, the average age of players obtaining eye injuries had increased to 26 years in 1984 from 14 years old in 1974. The converging evidence in the literature pertaining to non-concussion head injuries and facial protection in ice hockey suggests that visors and cages do indeed protect players against this form of head injury.

A few studies investigating the effect of facial protection on concussion have also been recorded, though mixed results were reported. A study examining the impact of face shield use on concussions in ice hockey (Benson et al., 2002) found that the use of full versus half face shields by intercollegiate ice hockey players greatly reduced the amount of playing time lost as a result of concussion. It was reported in the aforementioned literature by Stevens et al. (2006) that the use of a visor does not have a significant effect on the prevalence of concussion. In a study examining the mechanics of facial protection on impact attenuation, Lemair and Pearsall (2007) demonstrated that facial protectors can serve to attenuate impact accelerations below tolerance criteria for ice hockey helmet standards. The authors concluded that facial protectors reduced peak acceleration (PA) during impact, with cages allowing for a significantly lower PA than visors. While research to this point is inconclusive as to the effects of facial protection on the risk of concussion, it is clear that wearing facial protection significantly reduces the risk of non-concussion head injuries.

1.5 Decreased performance?

There is a perception in the hockey community that cages and visors impair the field of vision (Murdoch, 2001; Associated Press, 2005; Cox, 2005). Few scientific studies exist to address this concern. In a study examining the effects of visors and sports goggles on visual function, visors were reported to reduce peripheral vision (Ing et al., 2002). Eight subjects wore two different protective devices: an ice hockey visor and a sports goggle designed for hockey. All subjects underwent visual acuity, colour vision, contrast sensitivity, and Humphrey central 30° and peripheral 30° to 60° threshold perimetry tests with and without protective eyewear. While no significant differences were found in the visual acuity, colour vision, or contrast sensitivity tests, the mean deviation index values from the Humphrey tests (used to quantify vision loss in patients with glaucoma) were found to be significantly different for both eye protection conditions in comparison to the control condition (no eye protection). The results observed indicated that the hockey visor, as well as sports goggles, adversely affected peripheral vision, with greatest impact found in the far temporal field, greater than 60° from visual fixation. Unfortunately, the issue of the effect of this attenuation of vision on performance was not addressed. Other potential visual problems associated with visors not explored in this study include fogging, ice shaving condensation, scratches, glare, and visual distortion, particularly through the bottom of the visor.

In an experiment investigating the effect of protective sports eyewear on the peripheral visual field and a peripheral visual performance task, while not specific to ice hockey facial protection, seven different types of sports eyewear were tested (Gallaway et al., 1986). Subjects underwent peripheral visual field measures using a Goldmann Bowl Perimeter as well as a visual performance task using a Wayne Saccadic Fixator and Stik-Up attachments. The Goldmann Bowl Perimeter is a device in which fixation, retinal adaptation, and stimulus size and intensity can be controlled in order to measure degradation of the visual field. The Wayne Saccadic Fixator is a device which presents lights at 16 positions on the instrument's face. When a button next to an activated light is pressed, the light then moves to another random position. Subjects were instructed to press as many lights as possible in a 30 second period, undergoing all seven sports eyewear conditions and a control condition. The purpose of the study was to determine whether peripheral awareness, as measured with a visual performance task, was affected. It was concluded that the sports glasses did indeed restrict the visual field. The restrictions, however, did not translate into significant differences for the performance task.

A study examining whether there was significant visual field loss associated with wearing eye protection, again not specific to ice hockey facial protection, tested the visual field with and without eye goggles (Miller & Miller, 1993). The methodology included one of the authors being subjected to standard kinetic visual field testing with and without sports goggles. In contrast to aforementioned studies, no significant differences were revealed. Furthermore, the authors concluded that physicians, physical therapists, and trainers should encourage the use of protective eyewear and reassure athletes that their visual field would not be compromised.

The literature described in this section, largely the study by Ing et al., seem to suggest that ice hockey facial protectors, and more specifically visors, may cause some perturbation of the visual field. In ice hockey, a fast-paced sport that heavily relies on vision and reaction time, any impairment in the field of vision has the potential to lower one's level of play. Furthermore, a slight latency in one's response time could have effects on both performance and safety on the ice. To date, no studies have been reported examining the effects of ice hockey cages and visors on response time or kinematics in a goal directed task. To study this issue, the research design and parameter estimates as outline in related vision-task experiments may be adopted.

1.6 Response time and goal directed tasks

There are multiple studies that have examined response (RsT) or reaction time (RT) relating to goal directed tasks in response to visual cues. The average RT in these studies, as one would expect, are heavily dependent on their method of capture and, in some cases, even vary by definition (Thomas et al., 2005; Mokha et al., 1992; Crowe & O'Connor, 2001; Ando et al., 2001; Dwyer & White, 1974). For example, in a study evaluating visual evoked potentials, RT's, and eye dominance in cricket players, Thomas et al. (2005) judged RT as the mean time from illumination of one of five lights to a correct hit on a brass plate with a metal rod. The players were found to have a mean RT of 633 ms. No significant differences of RT were found between a control group and the experimental group in this study.

Another investigation examining the central and peripheral visual RT for three different stimulus sizes of soccer players as compared to a control group split RT into pre-motor and motor components (Ando et al., 2001). The pre-motor time was defined as the time between the stimulus and the appearance of an EMG recorded muscular action potential in the subject's forearm. Motor time was defined as the duration from the onset of the action potential to a key-press response. Results indicated that, while there were no differences between subject groups, peripheral visual RT was significantly longer than central visual RT due to an increment in pre-motor time. Mean RT's ranged from 242 to

286 ms while differences between central visual RT and the farthest peripheral visual RT means ranged from 6 to 30 ms.

An experiment observing peripheral area-intensity interaction in simple visual RT treated RT as the time from the illumination of a light to the release of a micro-switch trigger by the subject (Dwyer & White, 1974). Mean RT's were reported between 260 and 400ms.

These studies demonstrate the variability of RsT or RT as the procedure for its capture, experimental setup and methodology changes. It must be noted, however, that the variability of these measures is strictly between studies. Within each experiment, the mean times remain largely constant, with little variability (Thomas et al., 2005; Mokha et al., 1992; Crowe & O'Connor, 2001; Ando et al., 2001; Dwyer & White, 1974). Furthermore, additional studies have reported that visually directed movements are characterized by RT's of 200 to 500 ms (Desmurget et al., 1998; Georgopoulos et al., 1981; Prablanc et al., 1979). These RT's are supposed to reflect the time required for the central nervous system (CNS) to plan an adequate movement.

1.7 Upper body kinematics during a goal directed movement

It must be noted that, while there is some literature existing on the effect of sports goggles and visors on vision (Gallaway et al., 1986; Ing et al., 2002; Miller & Miller, 1993), none exists examining the effects of these hockey specific visual perturbations on kinematic changes in a goal directed task. This literature review section, however, gives examples of related studies whose results were extrapolated to create hypotheses of this study. Upper body angular kinematics and movement time indexes will be explored in an attempt to quantify possible kinematic differences between the three conditions. What can be extracted from present related literature is documentation of temporal and kinematic data relating to the upper body during goal directed movements, encompassing both perturbed and unperturbed conditions. These norms can then be used to hypothesize what might happen if indeed vision is perturbed by certain facial protectors.

Previous research has noted a coupling between the head and arm in goal directed movements. Smeets et al. (1996) compared head motions accompanying gaze shift while subjects executed different manual operations. Subjects were instructed to copy a pattern of blocks, presented in a model area, in a workspace area using blocks from a resource area. Four different instructions were given (conditions): (1) Subjects were instructed to copy the pattern of blocks in the model area, (2) subjects were instructed to touch the blocks in the resource area and touch the positions in the workspace area where the blocks should be moved to, (3) subjects were instructed to touch a block in the model area, touch a block of the same colour in the resource area, and touch the position in the workspace where the block should be moved to, and (4) subjects were instructed to not move their hand, but clearly fixate their gaze in the exact sequence of hand movements from condition (3). Through correlational analysis, they found a temporal coupling between the head and arm relating to initiation times, ending times, or peak velocities. They suggested that the precise timing of the head movement relative to the saccade changes in association with movement of the arm. A more recent study, noting that head movements display considerable flexibility and frequently diverge from eye movements, also noted that head movements appear to be linked to arm movements (Pelz et al., 2001).

Other research has noted specific chronological orders of the three-part eye, head and arm system, though, as will be described, diverging results have been reported. In an experiment aimed at investigating the coordination of multiple control actions (i.e. organization of motor systems controlling the eyes, head, and arm) involved in human horizontal gaze orienting or arm pointing to a common visual target (Suzuki et al., 2008), the experimenters looked at three conditions: (1) Gaze orienting with a combined eye saccade and head rotation (denoted as EH), (2) arm pointing with gaze orienting by an eye saccade without head rotation (EA), and finally a very similar condition to the one found in the present study, (3) arm pointing with gaze oriented by a combined saccade and head rotation (EHA). The results of this study showed that subjects initiated eye movements first with nearly constant latencies across all tasks. This was followed by head movement in the EH condition, arm movement in the EA condition, and head and then arm movements in the EHA condition. These results suggest that in a goal directed task such as this, the eye will initiate movement first, followed by the head, and then the arm. This chronology would make sense, as any strategy for organizing eye, head, and arm movements must include the differences in biomechanical properties of the 3 part system. The eye's inertial load is smallest, followed by the head and finger's, which have greater inertial loads (Biguer et al., 1982, 1984; Carnahan & Marteniuk, 1991; Gielen et al., 1984). It seems possible, and even likely, that temporal and kinematic patterns emerge based on the inherent dynamics of the physical system. Other studies, however, have shown that speed and accuracy of the limb movements directed toward a visual target affect the organization of eye, head, and hand movements (Carnahan, 1992; Carnahan & Marteniuk, 1991; Carnahan & Marteniuk, 1994). One such experiment specifically examined the speed versus accuracy effects on the chronological organization of the eye, head, and hand (Carnahan & Marteniuk, 1994). Results showed, in addition to the agreement that the pattern of organization depended on the speed and accuracy demands of the movement task, that movement termination patterns were remarkably consistent. The eyes always finished first, followed by the finger reaching the target, and then the head ceasing movement. While these studies leave in question the exact chronology of initiation of the eye, head and hand, clear evidence is demonstrated of this movement termination pattern.

Another factor of note is the implication of allocentric cues in the environment of testing. Allocentric cues can be defined as cues outside of one's self or, in this case, visual cues in a subject's surrounding environment. In a visuo-motor pointing task, Conti and Beaubaton (1980) measured the accuracy of response in situations differing in the visual information available as well as the speed of movement execution. In this experiment, vision of the hand and vision of the background were separately manipulated. Results demonstrated that moderately slow hand pointing was more accurate when performed in a structured visual background, as opposed to in the dark. The effect, however, was found to be absent in a rapidly executed pointing response. In addition, Velay and Beaubaton (1986) demonstrated that movement final accuracy was improved when a visual context was provided during movement planning only. This example of the contribution of environmental cues on target localization was duplicated in another such study (Coello & Grealy, 1997), but not in others (Rosetti et al., 1993; Blouin et al., 1993; Toni et al., 1996). It was noted in a review article by Desmurget et al. (1998) that this disparity may suggest that the implication of allocentric cues in target localization may be dependent on the experimental conditions present. It is possible that allocentric cues could be used to improve target localization during challenging conditions.

Vision of the hand has also been shown to be an important variable in goal directed movements. Prablanc et al. (1979) compared accuracy of visually directed movements performed under two separate conditions: (1) Vision of the hand was never allowed (FOL: full open loop) and (2) vision of the hand was allowed only in the static position preceding movement onset (DOL: dynamic open loop). The results demonstrated that movement accuracy was significantly better in the DOL condition than in the FOL condition. Desmurget et al. (1997) examined whether view of the right hand in the static position preceding movement could affect accuracy of pointing movements toward the subject's unseen left hand. The DOL condition, again, was found to have significantly higher end-point accuracy than the FOL condition. It was suggested that such a finding confirmed that knowledge of the initial upper limb configuration was crucial for accurate multi-joint movement planning. Results from the two aforementioned have been reproduced in various related studies (Elliott et al., 1991; Elliott, 1988; Desmurget et al., 1995; Rosetti et al., 1994; Ghilardi et al., 1995). This converging evidence suggests that if a subject's vision of their effector is perturbed there will be decreased accuracy and likely altered kinematics in a goal directed pointing movement.

Regarding joint kinematics, certain links have been found between the shoulder and elbow during goal directed pointing movements. A series of psychophysical investigations were carried out in the early 1980's by Soechting and Lacquanti (1981; 1983; 1984; Lacquanti & Soechting, 1982). These studies required human subjects to perform two-joint pointing motions in sagittal plane. They found that maximal angular velocities of the shoulder and elbow joints were reached at the same time. In addition, during the last part of movement, the ratio of angular velocities of these two joints was found to be constant. Further research by this pair (Lacquanti et al., 1986) exhibited that shoulder and elbow variations are linearly related for any given movement. It would be intriguing to find whether these maximal velocities of the shoulder and elbow were uncoupled under possible conditions of perturbed vision, such as ice hockey cages and visors.

If a target or effector is visually perturbed, it would be logical to suppose that joint kinematics would be altered for that specific target between a control condition and conditions of perturbed vision. The present study hopes to address the issue of whether differences in kinematics exist during a goal directed reaction time movement between three different ice hockey facial protectors. That is, does a possible visual perturbation lead to kinematic abnormalities? Potential deviations could manifest as chronological differences in kinematic strategies of the head/arm or shoulder/elbow systems. It is also possible that discrepancies are present between joint angle displacement and/or velocity.

1.8 Rationale for this study

Ice hockey is a high-performance sport involving numerous unpredicted collisions; hence, participation involves inherent risk of injury. To preclude and/or decrease the severity of physical injury, various prophylactic devices are worn by players. In the instance of faces, protection of the eyes is paramount; thus, facial protectors (or faceguards) secured to the player's helmet are commonly used. These facial protectors typically consist of translucent synthetic polymer visors or wire lattice cages. Though effective in their initial role, they may negatively affect performance; that is, they may degrade the player's field of vision (FOV) and in turn reduce the player's reaction time and subsequent movements. For this reason, some players have resisted voluntary use of facial protectors. While it has been reported in the literature that visors cause a reduction of peripheral vision (Ing et al., 2002), the effects of this reduction on response time have not yet been studied. Furthermore, while multiple experiments have been reported which look at differences in reaction in sports such as cricket and soccer (Thomas et al., 2005; Crowe & Connor, 2001; Ando et al., 2001), there have been no studies to date examining the effects of facial protection in ice hockey on response time, reaction time, movement time or kinematics during a goal directed task.

1.9 Purpose and hypotheses

The purpose of the study was to investigate the effects of three different facial protection conditions on response time and kinematics in a goal directed pointing task among varsity male and female hockey players. Three facial protection conditions were evaluated: helmet (control), helmet with visor (visor), and helmet with cage (cage). Previously obtained pilot data indicated that there was no difference in response time while wearing no helmet as opposed to wearing a helmet; thus, the helmet condition acts as the control.

It was hypothesized that longer response times would be observed when the subject was outfitted in a cage or visor, as opposed to the control group. Furthermore, it was expected that the major differences would most likely be seen in the reaction time segment of response time. Lastly, it was also hypothesized that kinematic differences (magnitude and chronological sequence) may be observed between the control condition and facial protection conditions. Differences in chronology of kinematic strategy were also noted.

2.0 METHODS

2.1 Subjects

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

2.2 Experimental setup and protocol

Testing took place in-lab (McGill Balance and Voluntary Movement Laboratory). Each 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 (figure 3). Three test conditions were examined wearing a helmet and: (1) no facial guard (control), (2) a cage, and (3) a visor (figure 1). Passive reflective markers were strategically placed on the subjects' body in accordance with the Vicon® full body plug-in gait model (Appendix 1).

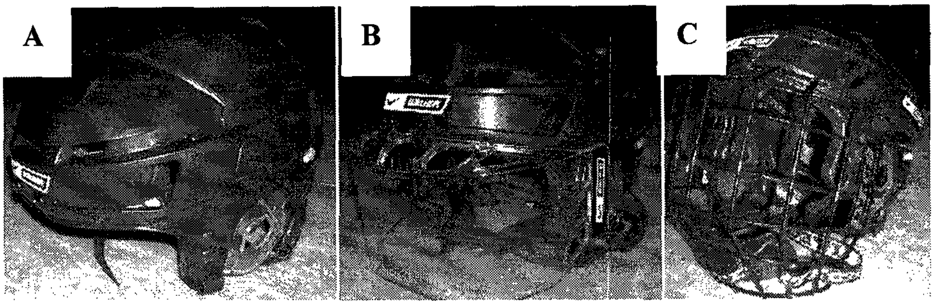

Figure 1: (A) Helmet (control), (B) Visor, and (C) cage.

The subjects began with the index finger of their preferred hand pressing a chest trigger (figure 2 (A)) 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 center of their visual field and, upon random illumination of lights in the array, remove their hand from the chest trigger and press the target as quickly as possible (figure 2 (B)). 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 setup is illustrated in figure 3.

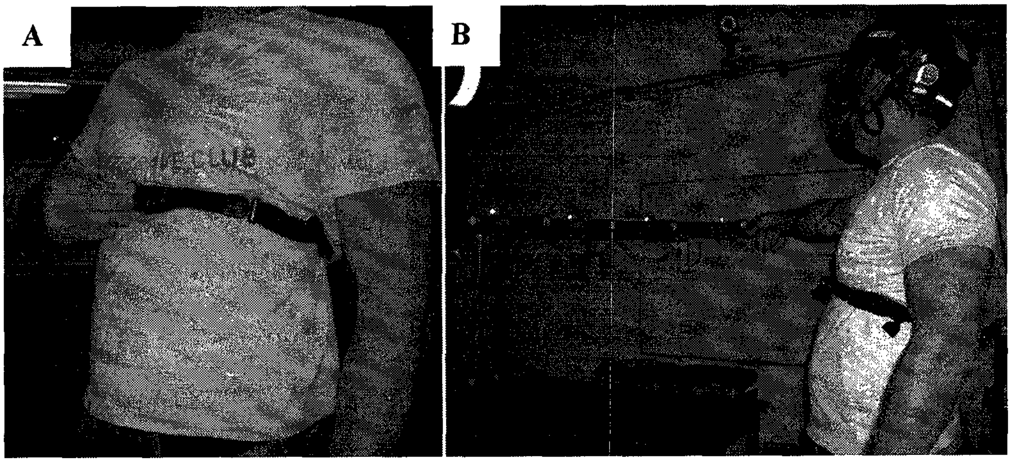

Figure 2: (A) The subject begins with their index finger pressing the chest trigger; (B) upon illumination of the light target the subject removes their hand from the chest trigger and presses the light trigger.

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 lights x 5 trials x 3 conditions = 195 trials).

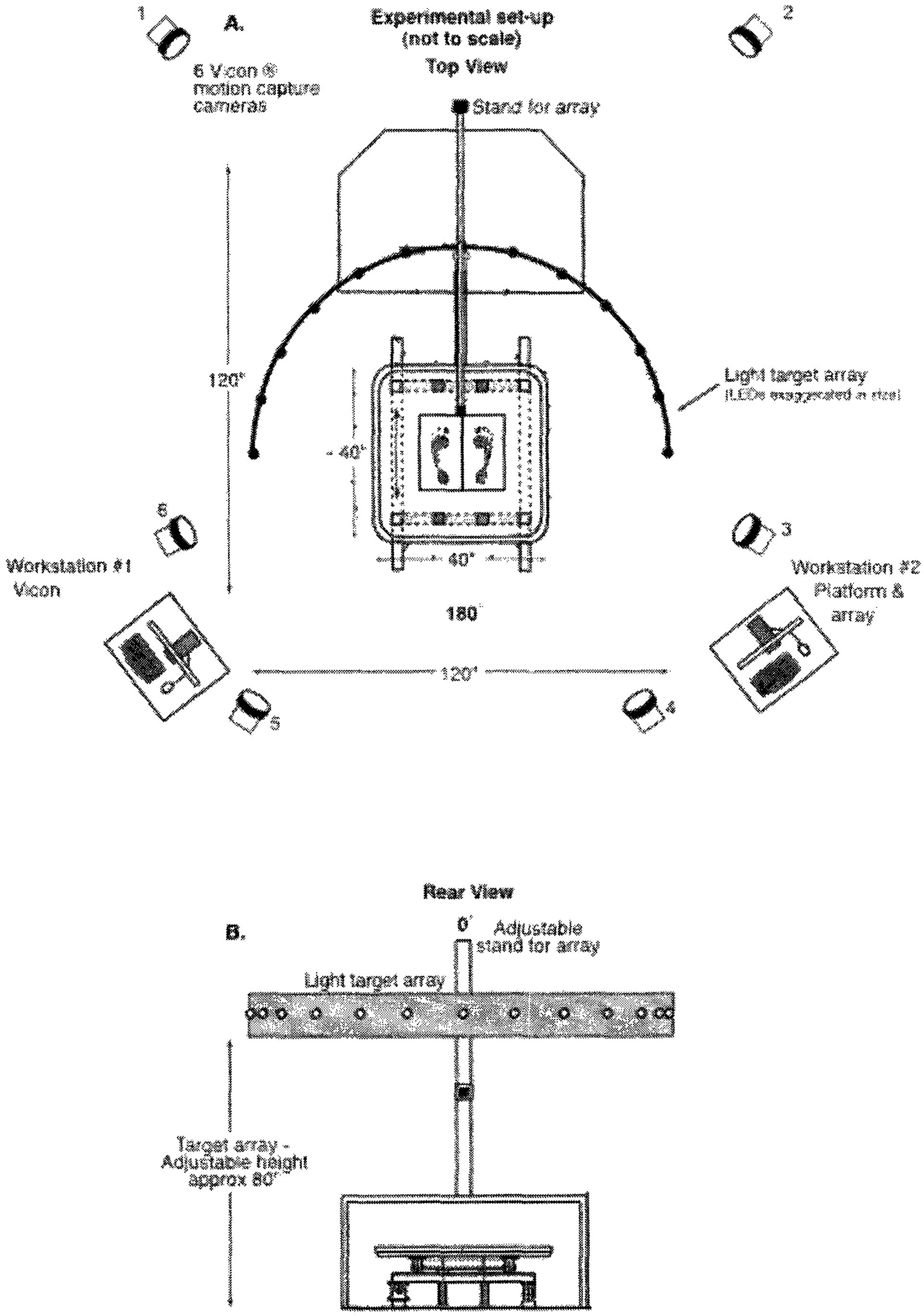

Figure 3: (A) Top view of experimental setup (180° array of LED's in clockwise direction from left to right); (B) Rear view of light target array and platform (Reproduced with kind permission from P. Stapley).

2.3 Pre-testing measurement and calibration

When the subject arrived at the testing facilities, they were introduced to the research staff. Following this, they were asked to read and sign a consent form (REB File #: 173-1207; Appendices 2 and 3). One of the research staff remained present in order to answer any questions the subject may have had and to explain the procedures to the subject.

Once the consent form was signed, the subject's shoulder height, reach, and plug-in gait measurements were taken. The shoulder height and reach measurements were used to calibrate the position of the light array. The light array was positioned so that the 13 light diodes were at the subjects shoulder height (or maximum array height) and 130% of the subject's reach. Lights at 0 and 180° (most lateral light on either side of the subject) were anterior-posteriorly aligned with the subject's acromio-clavicular joint.

Prior to a testing session, each of the motion capture system's six cameras were calibrated in order to capture every marker separately and discriminate between markers that were close to each other. These close markers may otherwise be circle-fit as only one marker. The 3-D capture volume was dynamically calibrated using a Vicon® 14 mm marker wand that was waved in the entire capture environment in order to be seen by all cameras placed at their respective locations. The dynamic calibration was considered successful if the residual error of all cameras was less than 0.20 mm. A static calibration was also performed in order to determine floor plane orientation. Finally, an L-frame with 30 mm reflective markers was placed on the platform, in the middle of the capture volume, in order to distinguish the floor plane.

2.4 Data acquisition

A six camera Vicon Mx system (Vicon®) was used to collect kinematic data of the head, neck and shoulders. 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 setup also allowed all markers to be seen by a minimum of two cameras in each trial in order to calculate their 3-D coordinates. The sampling rate of the Vicon Mx system was set at 200 Hz in order to retain adequate camera resolution. The 3-D Vicon environment can be seen in figure 4.

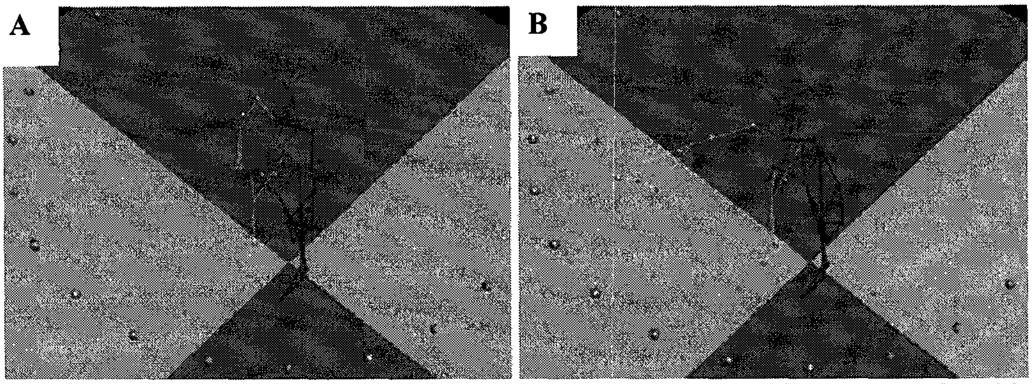

Figure 4: (A) The 3-D Vicon environment as the subject prepares for a trial and (B) as the subject moves to press the light trigger.

An I/O DAQ board and software program (National Instruments™, Labview™ 8) were used to operate the light array, synchronize it with the Vicon Mx system, and 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 was collected at 1000 Hz. Response time (RsT) was split into two components:

(1) Reaction time (RT) – Time between the illumination of the light diode and the subject removing their hand from the chest trigger

(2) Movement time (MT) – Time between the subject removing their hand from the chest trigger and depressing the light diode target;

where **RsT = RT + MT.**

In order for the Labview system to determine that a certain event has taken place, a 5 V spike occurred at the onset each of the 3 events:

(1) Illumination of the light diode

(2) Subject removing their hand from the chest trigger

(3) Subject depressing the light diode target

2.5 Data processing

Reconstructed 3-D 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®, 2007). Prior to the data processing, individual subject models were calibrated to label each marker for all trials. In order to ease the process of labeling trials, only 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 labeler 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 3-D 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 labeled 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% of the power spectral density was below 8Hz. Following the filtering routine, trials were run through Vicon Nexus' Dynamic Gate 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 finite difference algorithm implemented in MatLab 7.5 (MathWorks software®, 2007).

When dealing with temporal data (RsT, MT, and RT) 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.

2.6 Data analysis

The variables included in the data analysis, all compiled using custom Matlab files, are presented in table 1. The independent variables include the three facial protection conditions as well as each of the 13 light diode positions. The dependent variables can be split into two broad categories of response time data and kinematic data, which can be further broken down into sub-categories. The response time data included RsT, RT, and MT measures. The kinematic data included angular displacement at different points in the goal directed movement and peak angular velocity (PV) of the head, thorax, effecter shoulder and elbow, time index markers of peak displacement (PA_{indx}) and velocity (PV_{indx}), the difference between the time index markers of PV of the shoulder and elbow (PV_{diff}), and finally the difference between RT, as defined by the release of the chest trigger, and the time at which the head begins its movement (RT_{diff}). Displacement and velocity, their time indexes, PV_{diff}, and RT_{diff} acted as measures for changes in kinematic behavior due to facial protection condition.

The response time data analysis included all 28 subjects. For the kinematic data analysis the three left-handed subjects were omitted and three subjects were omitted due to technical difficulties with the Vicon® system at the time of data collection. These omissions still left a robust total of 22 subjects (n=22) included in the kinematic data analysis.

For the head and thorax, only the transverse plane (z-axis, yaw) was taken into account. When dealing with the shoulder complex, movement about all three functional axes was measured. Only the x-axis (flexion-extension) was taken into account for the elbow complex.

There are three displacement measures of note for each of the four body parts: (1) Trigger release angle (TA), (2) final angle (FA), and (3) peak angle (PA). TA is the angle at which the joint has deviated from its starting position (light diode illumination) at the point in time where the finger releases the chest trigger. FA is the angle at which the joint has deviated from its starting position at the point in time where the finger depresses the light target trigger. PA is the maximum deviation of the joint from its starting position encompassed in the time from the illumination of the random light diode to the depression of the light target trigger by the subject.

The acquisition of the dependent variable RT_{diff} is a process that warrants explanation. As discussed earlier in section 4.3, RT is defined as the time (in ms) between the illumination of a random light diode and the release of the subject's chest trigger. Time index of initiation of head movement was measured, using custom Matlab files, as the moment at which a forehead marker exceeds an absolute acceleration value of 250 mm/s^2 in the x-direction (anterior/posterior movement). The 250 mm/s^2 acceleration cut-off value was found to identify the beginning of motion. The x-direction was chosen due to the consistency of the acceleration curves across all lights. This time index was then subtracted from RT to achieve RT_{diff}, a value examining the chronology of the head/finger system in the pointing task.

Treating the data for outliers involved discarding outliers of two standard deviations above or below the mean. Once the data were treated for outliers, SPSS 15.0 (SPSS Inc., 2006) was used for statistical analysis. Dependent measures were analyzed using multivariate factorial repeated measures ANOVA for the number of lights (13 lights for response time data, 7 for kinematic data) and conditions (control, cage, visor), *alpha=0.05*. Significant main effects were explored using pairwise comparisons (with a Bonferroni correction) and Bonferroni post-hoc analysis.

Table 1: Summary of variables included in data analysis.

Variables		Definition	Scale	Hypotheses
Independent	**Dependent**			
Protective condition		*Type of facial protection:* (1) Control (2) Visor (3) Cage	Categorical (dichotomous)	
Light position		*Position of light diode in 180° light array:* • 13 light diodes, evenly spaced	Categorical (dichotomous)	
	Response time	1) Response time (RsT): reaction time + movement time 2) Reaction time (RT): Time from illumination of light diode to release of chest trigger. 3) Movement time (MT): Time from release of chest trigger to depression of light diode button.	Continuous	• Longer RsT, RT, and MT with cage and visor as compared to control
	Kinematics	*Displacement:* 1) Trigger release angle (TA): Relative displacement of head, thorax, shoulder and elbow from beginning of trial to release of chest trigger 2) Final angle (FA): Relative displacement of head (about the z-axis), thorax (z-axis), shoulder (all axes) and elbow (x-axis) from beginning to end of trial 3) Peak angle (PA): Maximum relative angle of head, thorax, shoulder and elbow from beginning to end of trial *Velocity:* 1) Peak velocity (PV): Maximum velocity of head, thorax, shoulder and elbow from beginning to end of trial *Time index data:* 1) Time index of PA (PA_{indx}) 2) Time index of PV (PV_{indx}) 3) Difference between time index of shoulder and elbow PV (PV_{diff}) *Comparison of head movement RT to chest trigger release RT:* 1) Difference between the time at which the chest trigger is released and the time at which the head begins its movement (RT_{diff})	Continuous	• Displacement measures for cage and visor differ from control • Greater peak velocity found in control condition • Larger time index data for cage and visor as compared to control • RT_{diff} will differ from control to visor and cage conditions

3.0 RESULTS

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

3.1 Response time data

Response time data (including reaction, movement, and response time; RT, MT, and RsT, repectively) will be addressed in this section of the results. Table 2 displays the grand mean of each dependent variable in each condition along with corresponding p-values. As can be noted, significant differences were present between RsT values ($p=0.019$), but not RT or MT values. Pairwise comparisons indicated that RsT of the cage condition was significantly lower than that of the control condition ($p<0.05$). In addition, a rank order in RsT latency was observed between the control, visor, and cage conditions, with means of 842.82, 855.23, and 866.15 ms, respectively. Similar ordering was observed for most light positions (figure 6) A post-hoc analysis revealed no further differences. Repeated measures analysis showed no significant differences for RT or MT. Figures 5 through 10 show the mean comparison of each condition as well as light-by-light comparisons of the three conditions for RsT, RT, and MT.

Table 1: Reaction, movement, and response time means (with standard error) and main effects p-values.

	Condition			
Dependent variable	**Control**	**Visor**	**Cage**	**p-value**
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
RsT (ms)	842.82 (18.22)	855.23 (19.45)	866.15 (18.06)	**0.019**

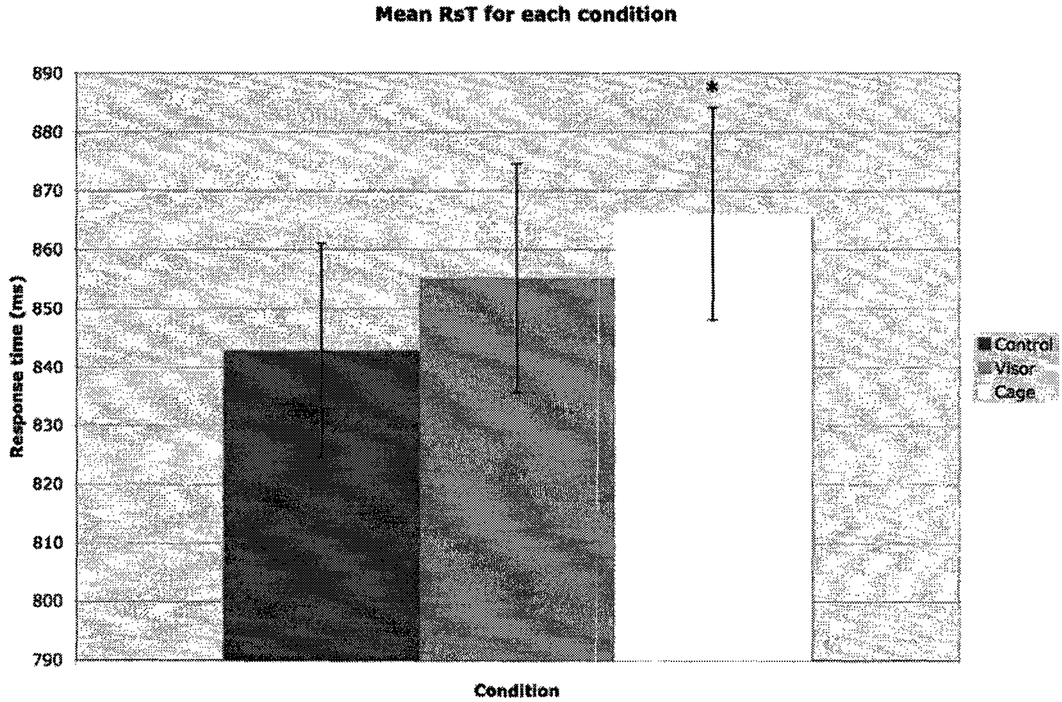

Figure 5: Mean (and standard error) of response times for each condition. * Indicates significant differences from the control condition

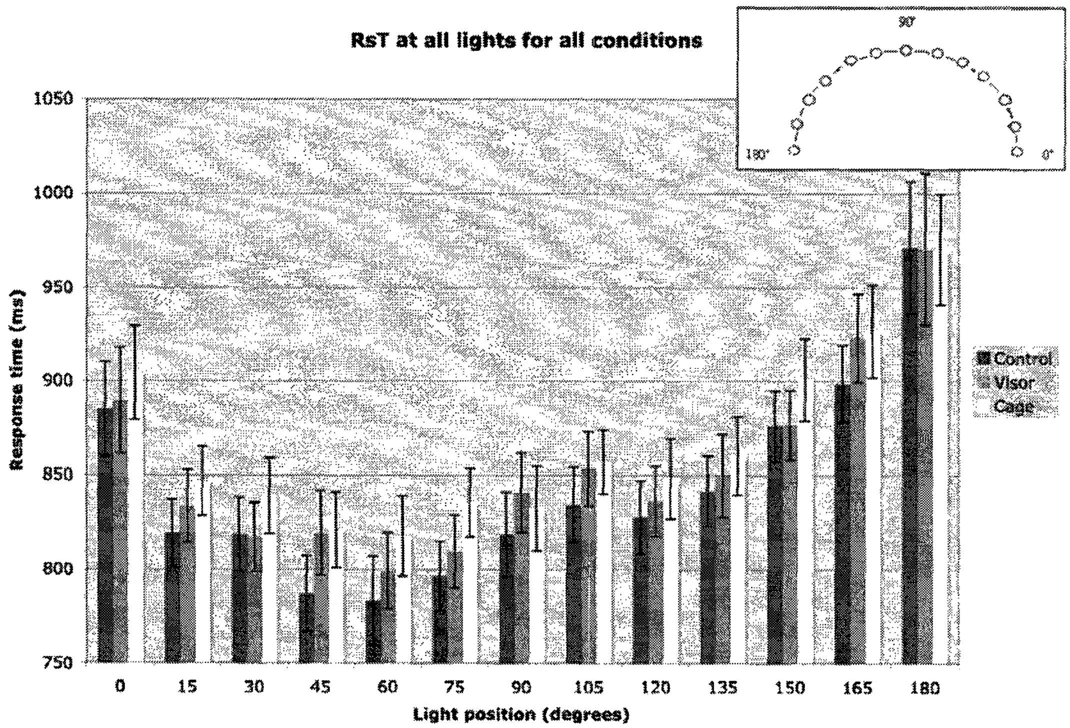

Figure 6: Response time means (and standard error) at each light for each condition.

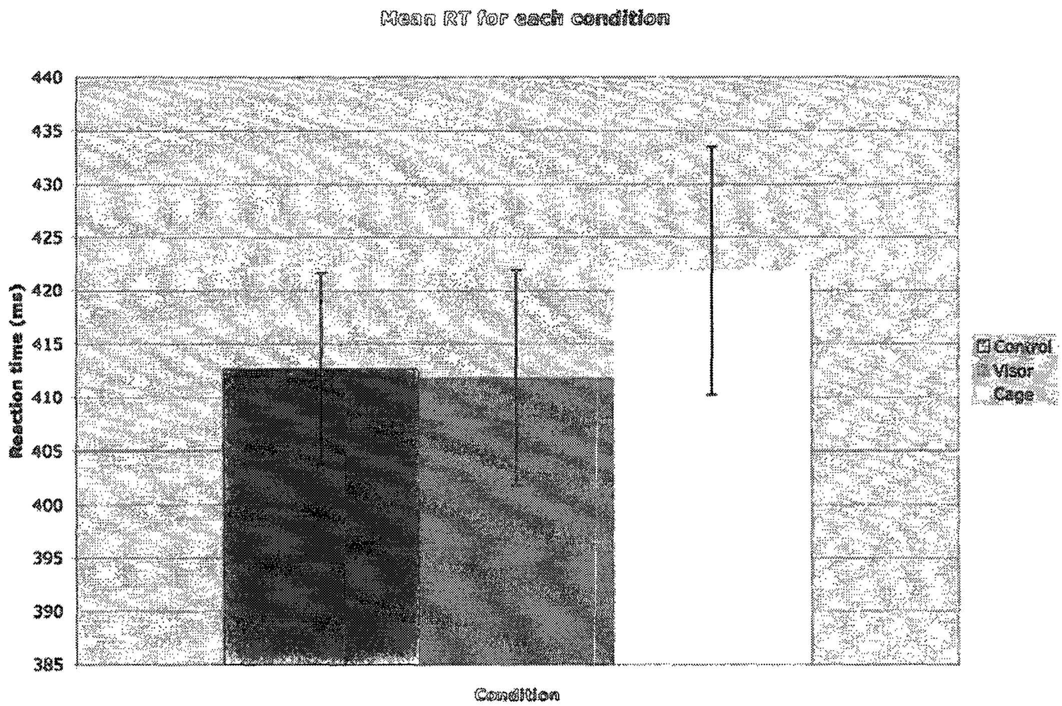

Figure 7: Mean (and standard error) of reaction times for all conditions.

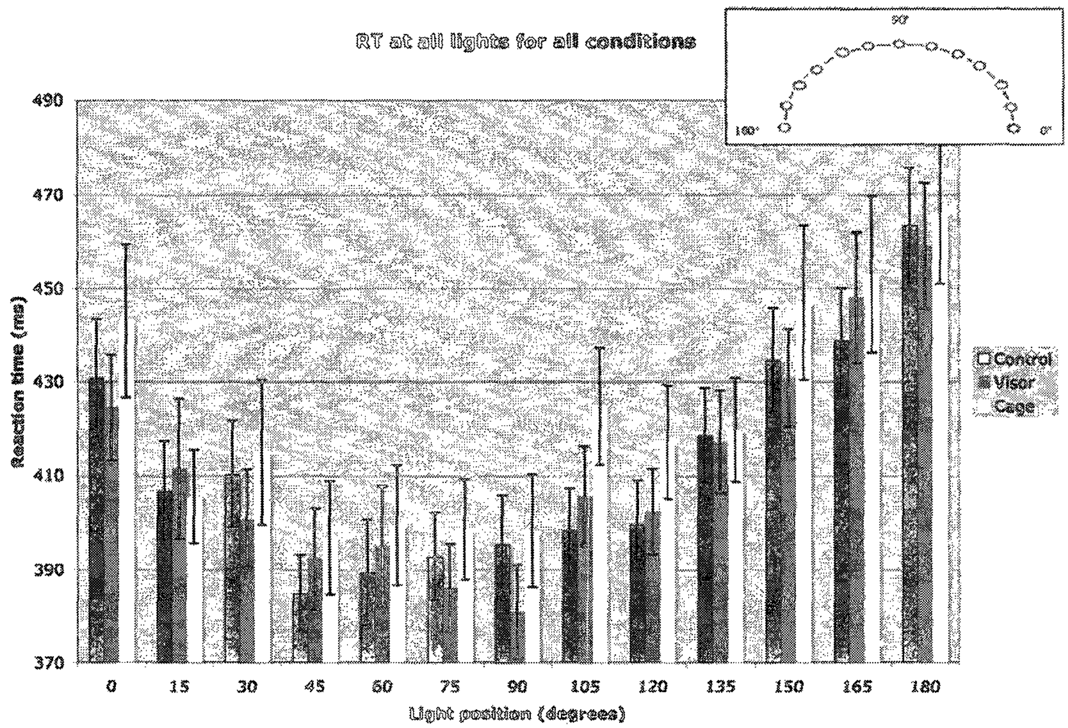

Figure 8: Reaction time means (and standard error) at each light for each condition.

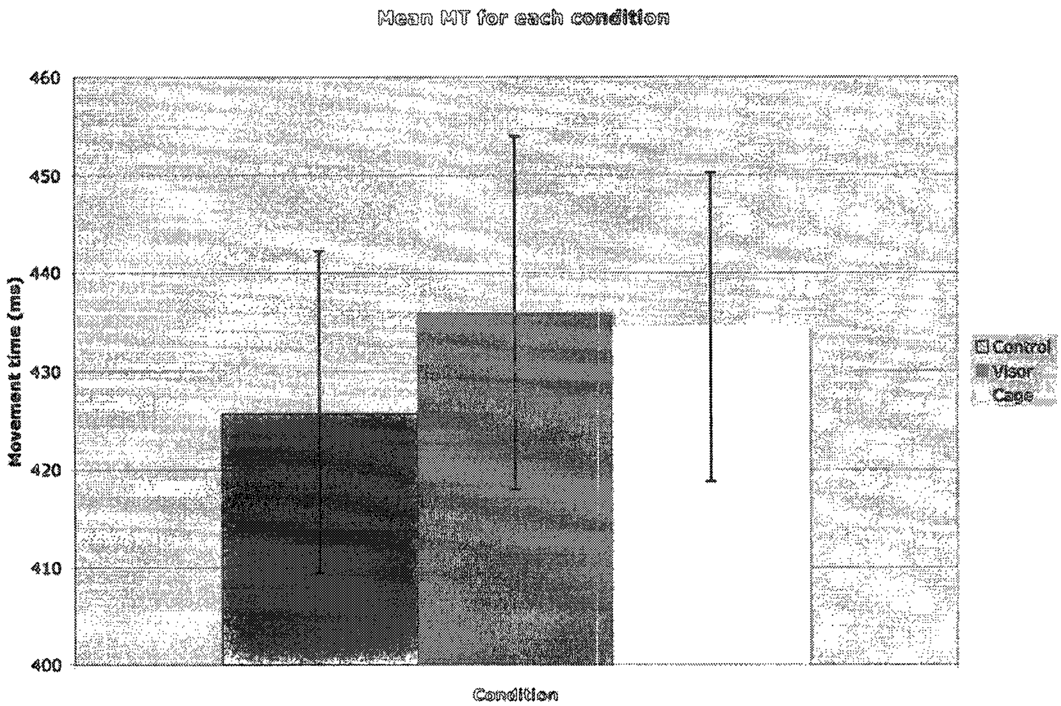

Figure 9: Mean (and standard error) of movement times for each condition.

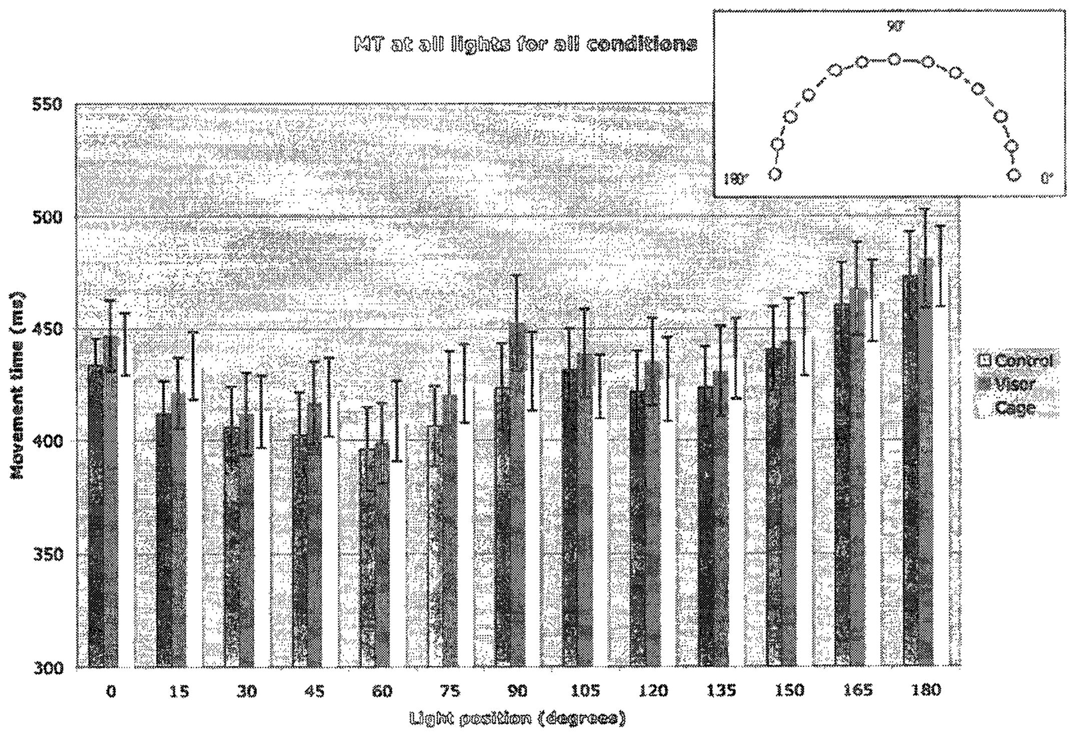

Figure 10: Movement time means (and standard error) at each light for each condition.

3.2 Kinematic data

3.2.1 Head (z-axis)

Kinematic variables of the head in the transverse plane were examined. Table 3 displays the results of the statistical analysis of these variables.

Table 2: Mean (and standard error) of all kinematic dependent variables for the head in the transverse plane.

Dependent variable	Control	Visor	Cage	p-value
TA (°)	10.56 (1.13)	9.13 (1.03)	9.05 (1.07)	**0.014**
FA (°)	39.55 (0.92)	39.77 (0.79)	39.82 (0.82)	0.754
PA (°)	40.72 (0.88)	40.98 (0.78)	41.00 (0.85)	0.672
PV (°/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

Repeated measures ANOVA found significant differences in TA (p=0.014). As shown in figure 11, pairwise comparisons showed a significance difference between the visor and control conditions of 1.43° (9.13° vs. 10.56°, p=0.032). While the difference in means of the control and cage conditions was greater than that of the control and visor (9.05° vs. 10.56°) the pairwise comparison revealed that, while 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° vs. 11.62°, p=0.031)(figure 12). Regarding TA, the 1.43° main effect and 3.07° post-hoc discrepancies uncovered, while statistically different, are likely due to small variance values and do not likely amount to functionally differences in movement.

The PV_{indx} variable also yielded significant results (p=0.000). As shown in figure 13, pairwise comparisons showed that this significance existed both between the control and cage conditions (89.71 ms vs. 107.84 ms, p=0.001) as well as between control and visor conditions (89.71 ms vs. 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 vs. 93.33 ms, p=0.040) (figure 14).

As can be noted in table 3, repeated measures ANOVA showed no other significant differences between any conditions for any of the other dependent variables when examining the motion of the head about the z-axis.

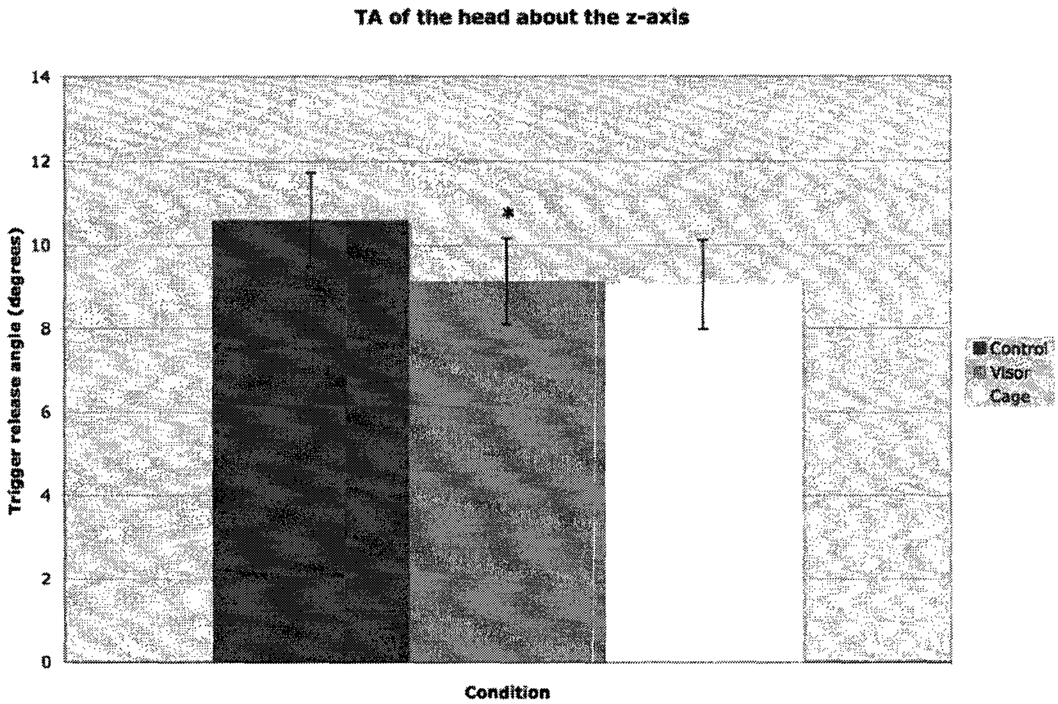

Figure 11: Mean (and standard error) of trigger release angles of the head about the x-axis for all conditions. * Indicates significant differences from the control group.

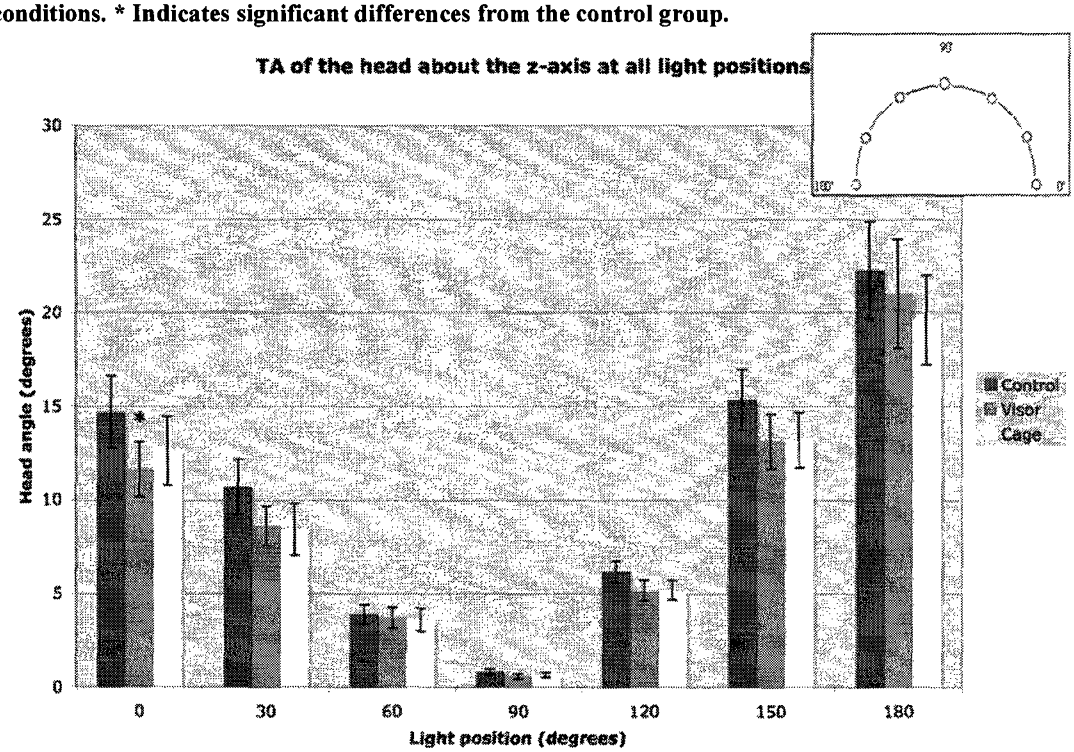

Figure 12: Mean (and standard error) of the trigger release angles of the head about the z-axis at all light positions for each condition. * Indicates significant differences from the control condition.

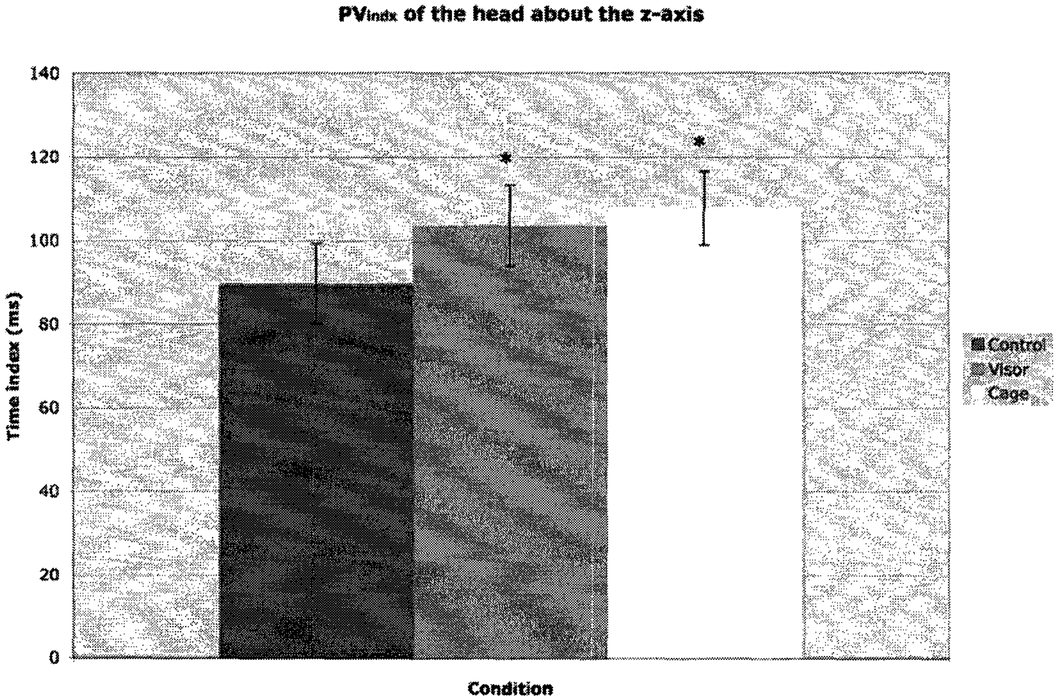

Figure 13: Mean (and standard error) of time indexes for peak velocity of the head about the z-axis for all conditions. * Indicates significant differences from the control condition.

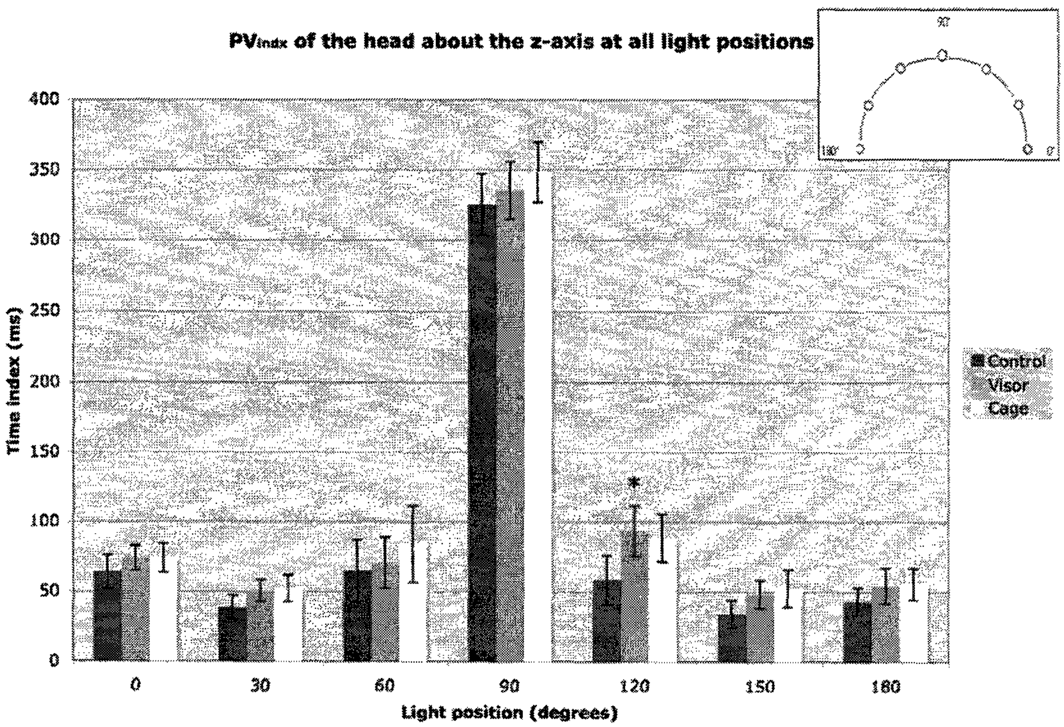

Figure 14: Mean (and standard error) of time indexes for peak velocity of the head about the z-axis at all light positions for each condition. * Indicates differences from the control condition.

3.2.2 Thorax (z-axis)

Results of the statistical analysis of the kinematic dependent variables of the thorax in the transverse plane (z-axis) are displayed in table 4. As can be noted through this table, no dependent variables were found to be significantly different across conditions.

Table 3: Mean (and standard error) of all kinematic dependent variables for the thorax in the transverse plane.

Dependent variable	Control	Visor	Cage	p-value
TA (°)	3.37 (0.44)	3.39 (0.50)	3.45 (0.50)	0.925
FA (°)	40.32 (0.61)	40.40 (0.69)	40.94 (0.76)	0.424
PA (°)	40.72 (0.61)	40.83 (0.69)	41.38 (0.74)	0.314
PV (°/s)	131.00 (5.35)	130.31 (5.31)	131.74 (5.58)	0.796
PA_{indx} (ms)	851.71 (23.55)	854.76 (23.22)	858.66 (22.10)	0.381
PV_{indx} (ms)	204.82 (11.68)	204.24 (11.54)	204.71 (11.19)	0.992

3.2.3 Shoulder (all axes)

3.2.3.1 x-axis

Results of the statistical analysis of the kinematic dependent variables of the shoulder about the x-axis (flexion/extension) are displayed in table 5. As can be noted through this table, no dependent variables were found to be significantly different across conditions.

Table 4: Mean (and standard error) of all kinematic dependent variables for the shoulder about the x-axis.

Dependent variable	Control	Visor	Cage	p-value
TA (°)	2.83 (0.39)	2.95 (0.46)	3.25 (0.49)	0.088
FA (°)	55.96 (1.45)	55.12 (1.41)	55.98 (1.50)	0.332
PA (°)	59.58 (1.28)	58.52 (1.29)	59.53 (1.41)	0.137
PV (°/s)	273.96 (9.93)	264.11 (8.30)	269.46 (10.23)	0.120
PA_{indx} (ms)	790.39 (20.04)	794.54 (19.22)	804.79 (19.84)	0.314
PV_{indx} (ms)	150.98 (7.71)	155.49 (8.44)	149.26 (7.99)	0.160

3.2.3.2 y-axis

Results of the statistical analysis of the kinematic dependent variables of the shoulder about the y-axis (abduction/adduction) are displayed in table 6. As can be noted through this table, no dependent variables were found to be significantly different across conditions.

Table 5: Mean (and standard error) of all kinematic dependent variables for the shoulder about the y-axis.

Dependent variable	Control	Visor	Cage	p-value
TA (°)	2.64 (0.34)	2.75 (0.44)	2.88 (0.42)	0.349
FA (°)	69.01 (3.12)	68.60 (3.28)	69.95 (2.96)	0.196
PA (°)	69.91 (3.12)	69.61 (3.37)	70.79 (3.00)	0.303
PV (°/s)	374.60 (33.10)	373.52 (41.46)	371.38 (31.90)	0.927
PA_{indx} (ms)	861.98 (24.30)	869.97 (24.91)	872.57 (23.14)	0.525
PV_{indx} (ms)	265.63 (9.18)	270.41 (9.05)	265.35 (8.59)	0.268

3.2.3.3 z-axis

Results of the statistical analysis of the kinematic dependent variables of the shoulder about the z-axis (internal/external rotation of the humerus) are displayed in table 7. As can be noted through this table, no dependent variables were found to be significantly different across conditions.

Table 6: Mean (and standard error) of all kinematic dependent variables for the shoulder about the z-axis.

Dependent variable	Control	Visor	Cage	p-value
TA (°)	1.84 (0.24)	1.56 (0.15)	1.75 (0.23)	0.190
FA (°)	83.44 (3.64)	82.93 (3.52)	83.18 (3.45)	0.915
PA (°)	84.84 (3.75)	84.54 (3.67)	84.86 (3.50)	0.935
PV (°/s)	439.63 (35.58)	440.71 (42.32)	440.97 (37.32)	0.989
PA_{indx} (ms)	854.42 (24.07)	855.89 (24.60)	865.76 (24.54)	0.578
PV_{indx} (ms)	240.58 (9.62)	243.63 (8.63)	237.74 (7.73)	0.189

3.2.4 Elbow (x-axis)

Results of the statistical analysis of the kinematic dependent variables of the elbow about the x-axis (flexion/extension) are displayed in table 8. As can be noted through this table, no dependent variables were found to be significantly different across conditions.

Table 7: Mean (and standard error) of all kinematic dependent variables for flexion/extension of the elbow.

Dependent variable	Control	Visor	Cage	p-value
TA (°)	1.53 (0.23)	1.53 (0.22)	1.65 (0.26)	0.361
FA (°)	88.75 (1.22)	89.55 (1.24)	89.50 (1.24)	0.182
PA (°)	89.30 (1.23)	90.11 (1.25)	90.01 (1.26)	0.189
PV (°/s)	375.65 (14.98)	381.05 (19.34)	377.67 (16.33)	0.795
PA_{indx} (ms)	865.67 (23.69)	871.11 (25.23)	873.80 (22.60)	0.647
PV_{indx} (ms)	213.21 (9.37)	214.81 (8.75)	211.80 (8.71)	0.705

3.2.5 Chronologic data

Results of the statistical analysis of the chronology of the head/arm system as well as the shoulder/elbow system are reported in table 9. As can be noted through this table, no dependent variables were found to be significantly different across conditions.

Table 8: Mean (and standard error) of all chronologic dependent variables.

Dependent variable	Control	Visor	Cage	p-value
RT_{diff} (ms)	151.36 (8.31)	148.28 (9.09)	148.97 (8.59)	0.733
$PV_{diff(x)}$ (ms)	18.11 (12.88)	19.14 (10.36)	23.75 (9.50)	0.466
$PV_{diff(y)}$ (ms)	48.06 (9.55)	51.37 (8.74)	49.19 (8.87)	0.641
$PV_{diff(z)}$ (ms)	21.96 (8.97)	24.52 (8.08)	20.84 (8.16)	0.502

4.0 DISCUSSION

While facial protectors are essential to prevent eye and dental injuries they must not encumber vision and, in turn, performance. Scant information exists about the latter. Hence, to identify in part the unknown performance detriment, the purpose of this study was to investigate the effects of different facial protection conditions on response time and kinematics in a goal directed pointing task. Three facial protection conditions were evaluated: uncovered (control), visor, and cage. This section will evaluate the results found and interpret their implications. Lastly, in light of the procedural context, future recommendations for research will be proposed.

4.1 Response time (RsT)

To restate the original hypothesis, longer RsT was expected when subjects wore a cage or visor, as opposed to the unencumbered visual (control) condition. More specifically, it was anticipated that major differences would be due to the RT segment of RsT. Thus, the null hypothesis (H_o) stated that there would be no significant differences between conditions for RT, MT, and RsT. The alternative hypothesis (H_a) stated that differences would be observed between conditions for RT, MT, and RsT.

Regarding RsT, H_o was rejected (p=0.019). The main difference observed was 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 RsT means was observed between the three conditions (control<visor<cage; 843, 855, and 866 ms, respectively). While no statistical differences between conditions were found for RT and MT variables, time

measures with the cage were consistently greater than without (i.e. 9.17 ms and 8.70 ms differences; p=0.085 and 0.153, respectively). Thus, these longer increases culminated into longer RsT times.

To place this in perspective, the 23 ms difference between the control and cage RsT means represents a functional significant effect. For instance, in Ando et al.'s (2001) study, 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 peripheral visual RsT (stimulus in the periphery of the field of vision) and central visual RsT (stimulus at the center of the field of vision). Thus, the 23 ms difference found in the current study is similar in magnitude to other studies' contrasting conditions.

With respect to RT, the observed range of mean values fall within those noted in the literature, ranging of 200 to 500 ms (Ando et al., 2001; Desmurget et al., 1998; Georgopoulos et al., 1981; Prablanc et al., 1979). For instance, a study which in part examined pointing by hand with an unrestricted visual feedback towards a randomly illuminated target (Prablanc et al., 1979) demonstrated a range of mean RT's from 332 to 402 ms. Thus, the magnitude of RT's from the present study are comparable to prior 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 RT's are in agreement with prior literature (Ando et al., 2001; Brebner and Welford, 1980). Variation in visual stimuli perceived by different areas of the eye presumably produce different RT's, 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) (Brebner and Welford, 1980). Across targets similar rank order trends and magnitude differences between conditions were observed. Hence, visors and cages affected RT similarly across the visual field.

In a fast paced sport such as ice hockey, the 23 ms RsT discrepancy between the control and cage conditions may represent the difference between failure and success in various performance measures (Haché, 2002). 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 (Li et al., 2005), of which 23 ms makes up a notable portion. Consequently, the prolonged RsT 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 RsT delays.

4.2 Kinematics

It was hypothesized that kinematic differences (magnitude and chronological sequence) would be observed between the control condition and facial protection conditions. Therefore, H_o stated that no kinematic differences would be observed between conditions for all kinematic dependent variables. H_a stated that kinematic differences would be observed between conditions for the kinematic dependent variables.

However, upon examination of the kinematic variables few significant differences were observed. For all dependent variables with regard to the thorax, shoulder and elbow there was a failure to reject H_o. In contrast, significant differences were discovered for the head about the z-axis (yaw, or side-to-side orientation). A particular variable of note was PV_{indx} (time index of peak velocity) of the head. Differences existed between both the control and visor (14 ms; $p<0.003$) and the control and cage conditions (18 ms; $p=0.001$) were observed. Therefore, H_o was rejected. This finding did not come unexpectedly, as the differences between conditions of RT, MT, and RsT means likely correspond to this difference of PV_{indx}. While there was an ascending rank order observed from control to visor to cage, respectively, no significant difference was observed between the visor and cage conditions. Similar rank orders for PV_{indx} were not observed for any other body parts examined. The significance of the head's PV_{indx} likely reflects the resulting delay in movement caused by increased reaction and movement times.

As noted in the results, head movement initiation did in fact precede hand movement initiation (RT_{diff}), similar to reports by Suzuki et al. (2007). This chronologic sequence and that of shoulder and elbow peak velocity index (PV_{diff}), however, were not found to be significantly affected by conditions. Nor was there any differences found within any kinematic variables for the thorax, shoulder, and elbow. While it seems that the perturbed vision due to the cage did alter RsT, 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. (1998) and could allow for kinematics of this goal directed pointing motion to be left largely unaffected. That is, visual cues around 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 cage conditions, with means corresponding to the rank order observed in RsT means (control<visor<cage). Examination of kinematic variables confirmed that, while a latency of movement was observed, movement patterns remained largely intact throughout all conditions.

4.3 Limitations

This study was performed in-lab in order to control the environment as much as possible, therefore enabling one to attribute differences in response time 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 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.

4.4 Suggested future direction of research

The author is hopeful that this research will be expanded upon and suggests that three major additions be made to future studies in this field: (1) direct accuracy measures, (2) increased vertical area of the light array, and (3) expand to on-ice and in-game performance conditions.

To address the first point, while speed of response and kinematics were explored, no direct accuracy or precision measures were taken. It would be beneficial to find the distance from the center of a target that the subject impacts upon pointing and compare these measures between conditions in order to determine the effects that the visual perturbation of ice hockey facial protectors has on precision and accuracy during these tasks.

It would also be beneficial to add the vertical dimension in addition to the horizontal plane of the light array. During this study, the light array consisted of 13 light triggers mounted onto a 180° arc of a single transverse plane. Inclusion of vertical dimension to the array (and light triggers) may allow for one to acquire an increased understanding of the effect 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, it may be prudent to consider using other three dimensional environments that not only has horizontal and vertical dimension, but varied depths of targets. This augmentation of the experimental setup would allow for data collection in an atmosphere that presents the challenges of a true three dimensional world, thus, allowing for an increased external validity to the complex environment faced in the sport of ice hockey.

Finally, it would be helpful to expand this research to on-ice conditions examining shooting accuracy, puck handling, defensive measures, and even competitive game situations. 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 analyze the effects they have on shooting kinematics, accuracy, and precision. Additionally, 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 target other important areas such as the ability of players to prepare oncoming body contact. These on-ice studies would afford a great deal of external validity to this vein of research.

5.0 CONCLUSION

The results of this study showed that, while kinematics remained largely unaffected, there was an increased RsT as well as increased time delay at which peak velocity of the head was reached from the control condition to the cage condition, indicating that the use of a cage did in fact degrade performance in a goal directed pointing task. When comparing the visor to the control condition, while an increased latency of peak velocity still existed, RsT remained unaffected. These latencies in RsT and PV_{indx} indicate that a certain decrease in vision exists while wearing the cage and to a lesser extent the visor. A slight increase in response latency at the elite level of ice hockey has the potential to limit a participant's ability 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 and thus should still be worn at all levels of play. However, the results of this study suggest that the decreased vision through the use of a cage increases RsT. Optimization of 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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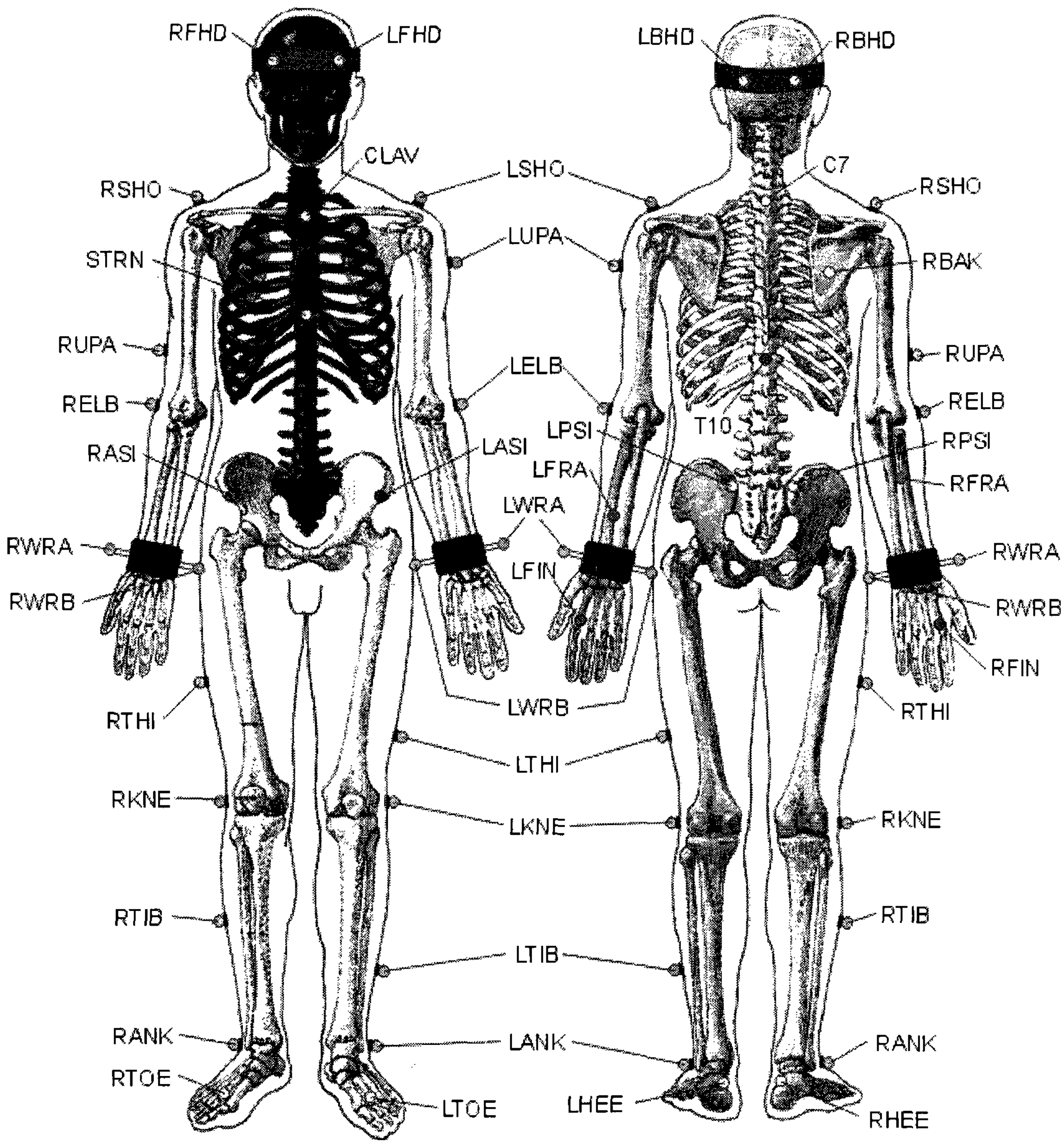
APPENDIX 1 - Vicon® Plug-in-Gait Marker Placement



APPENDIX 2 – Subject Information and Consent Document

INFORMATION AND CONSENT DOCUMENT

Investigator: Patrick M. Dowler M.Sc. candidate
David J. Pearsall Ph.D.
Biomechanics Laboratory, Department of Kinesiology and Physical Education, McGill University

Statement of Invitation
You are invited to participate in a research project conducted by the above named investigator. This research project will be performed in the Balance and Voluntary Movement Laboratory of the Department of Kinesiology and Physical Education, McGill University, located at 475 Pine Ave West, Montréal, Québec H2W 1S4. You are asked to come to one experimental session that will each last up to 1 hour. I greatly appreciate your interest in my work.

Purpose of the Study
The purpose of this pilot study was to investigate the effects of three different facial protection conditions on reaction and movement time as well as the changes in behaviour of kinematics. You will be required to point to illuminated targets placed at different equidistant positions from your midline when you stand, under 3 conditions:

1. Wearing a hockey helmet
2. Wearing a hockey helmet with a visor
3. Wearing a hockey helmet with a cage

Your participation in this study involves:
1. Providing informed consent prior to the experimental session,
2. Providing data concerning your physical attributes (e.g., height, gender, age, and different anthropometric segment measurements),
3. Performing three conditions (helmet, visor, cage) of pointing movements to light targets in 13 different directions. This will involve simple, undisturbed movements of your arm and finger to the light targets. The procedures listed below are common to the two experimental sessions:
    a. You will stand upright with the index finger of your preferred arm on a height-adjustable switch at your midline,
    b. You will be equipped with up to 10 reflective and adhesive markers placed at different joint centres on both sides of your body.
    c. You will be outfitted with a hockey helmet, hockey helmet with a cage, or hockey helmet with a visor. The helmet will have an eye-tracking device attached to its front boss.
    d. You will be asked to conduct up to 65 trials per condition

Risks and Discomforts
It is envisaged that you will encounter no significant discomfort during these experiments. There are no risks associated with these experiments. An experimenter will stand close to you at all times during the sessions.

Benefits
There are no personal benefits to be derived from participating in this study. Documenting the effects of different faceguards on reaction time has the potential to both increase the on-ice hockey performance as well as decrease the inherent injury risks one is exposed to in a competitive game situation.

Confidentiality
All the personal information collected during the study you concerning will be encoded in order to keep their confidentiality. These records will be maintained at the Biomechanics Laboratory by Dr. David Pearsall for 5 years after the end of the project, and will be destroyed afterwards. Only members of the research team will be able to access them. In case of presentation or publication of the results from this study nothing will enable your identification.

Inquiries Concerning this Study
If you require information concerning the study (experimental procedures or other details), please do not hesitate to contact *Patrick M. Dowler*, at the numbers or addresses listed at the top of this document.

Responsibility clause
In accepting to participate in this study, you will not relinquish any of your rights and you will not liberate the researchers nor their sponsors or the institutions involved from any of their legal or professional obligations.

Consent
Please be advised that your participation in this research undertaking is strictly on a voluntary basis, and you may withdraw at any time.

A copy of this form will be given to you before the end of the experimental session.

CONSENT

I, ______________________________________, AGREE TO VOLUNTARILY PARTICIPATE IN THE STUDY DESCRIBED ABOVE ABOUT THE COORDNIATION OF POSTURE AND VOLUNTARY MOVEMENT.

I HAVE RECEIVED AND READ A DETAILED DESCRIPTION OF THE EXPERIMENTAL PROTOCOL. I AM FULLY SATISFIED WITH THE EXPLANATIONS THAT WERE GIVEN TO ME REGARDING THE NATURE OF THIS RESEARCH PROJECT, INCLUDING THE POTENTIAL RISKS AND DISCOMFORTS RELATED TO MY PARTICIPATION IN THIS STUDY.

I am aware that I have the right to withdraw my consent and discontinue my participation at any time without any prejudices.

Signatures

SUBJECT

______________________________ ______________________________
(signature) (print name)

RESEARCHER

______________________________ ______________________________
(signature) (print name)

Date: ________________________