The use of vision during offensive ice hockey skills

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Abstract

The purpose of this study was to determine if any differences in gaze characteristics existed between accurate and inaccurate shooting groups. A total of twelve subjects participated in this study; five of which were placed in the AS group (accurate) and seven in the IS group (inaccurate) post-hoc. The task required the subjects to receive a pass from an assistant, followed by the execution of a wrist shot at one of two targets on net. Each subject performed 90 total shots which included 60 shots with a time pressure condition and 30 shots without any time constraints. Passes were directed to either the forehand or backhand of the subject for the time pressure task, while during the task with no time pressure passes were only directed to the forehand. Each subject executed the protocol wearing an eye tracking system which identified their eye-line-of-gaze which was recorded at 60 Hz. The results indicated that for the forehand reception / time pressure condition the AS group gazed at the net and target (combined time) for a significantly longer ($p < 0.049$) duration (0.191 s ± 0.020) prior to the shot release, than the IS group (0.136 s ± 0.017). The backhand reception / time pressure condition yielded similar results regarding this gaze characteristic. The results of the forehand reception / time pressure condition also revealed that the AS group was able to shift their gaze from the puck (on the ice) to the net in a significantly shorter ($p < 0.014$) duration of time (0.157 s ± 0.023) than the IS group (0.238 s ± 0.019). When no time constraints were placed on the subjects, no significant differences in gaze characteristics were found between the two accuracy groups. However, the AS group was able to significantly improve ($p< 0.042$)

their accuracy results in the no time pressure condition (M=57.3% to 70.7%) while the IS group (M=28.1% to 30.0%) was not able to do so. The results of the present study suggest that accurate shooters in ice hockey are able to transfer their gaze to the net in a significantly shorter duration of time which ultimately allows them to gaze at the net and target for a significantly longer duration of time in comparison to an inaccurate shooter. These factors in combination with the kinematics of the shooter may help to determine the accuracy of a shooter in ice hockey. Verifying if these same differences exist, or if there are any more discrepancies when a goaltender is present in the net may be the next step for future studies.

Resume

Le but de cette étude était de déterminer si des différences existaient entre des joueurs de hockey de précision différente au niveau des caractéristiques visuelles lors de tirs du poignet. Un total de douze sujets ont participé à cette étude; cinq ont été placés dans le groupe AS (précis) et sept dans le groupe IS (inexactes) post-hoc. La tâche des sujets consistait à recevoir une passe à partir d'un assistant, suivie par l'exécution d'un tir des poignets à l'une des deux cibles sur le filet. Chaque sujet a effectué 90 tirs au total, parmi ces derniers 60 étaient effectuer avec une limite de temps (pression) et 30 tirs sans aucune contrainte de temps. Chaque sujet a exécuté le protocole portant un modèle 501 Head Mounted Eye Tracker (Applied Science Laboratories, Bedford, MA) qui a permis d’identifier et d’enregistrer la ligne de vision, enregistré à 60 Hz. Les résultats indiquent que pour la condition sous pression, le groupe AS regardait la cible à atteindre pour une plus longue durée que le groupe IS avant la rondelle ne quitte le bâton. Les résultats ont également révélé que le groupe AS a été capable de déplacer leur regard de la rondelle (sur la glace) au filet plus rapidement. Quand aucune contrainte de temps n’était imposée aux sujets, aucune différence significative dans les caractéristiques des regards ont été trouvés entre les deux groupes de précision. Cependant, le groupe AS a été en mesure d'améliorer considérablement la précision de leurs résultats lors des lancers sans pression. Pour de futures études, il serait important

de déterminer si ces mêmes différences existent, ou s'il ya des écarts plus grand lorsqu’un gardien de but se trouve devant le filet.

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Chapter 1: Introduction

1.0 Introduction

Ice hockey is an extremely fast-paced sport which requires the combination of a variety of skills. The different skills include skating, stick handling, shooting as well as checking and within each of these groupings there are several variations or subsets of the movements (Pearsall, Turcotte, & Murphy, 2000). With the speed of the sport and the open conditions, a player's perception, decision making, and reaction times are as important as the movements defining skill level (Connolly, 1977). Mental awareness and physical skills are both necessary for a hockey player to be successful at a high level. In all open sports, the athletes must be aware of their surroundings by using their tactile, auditory, and visual senses. These senses are not only useful for athletes to be conscious of their environment but also for the acquisition and performance of a given skill. Passing and shooting skills in ice hockey are necessary for every player but there is a wide range of techniques as well as skill levels. Both of these skills require the player to aim at a target using vision and in some cases memory. Brouwer and Knill (2007) found that humans appear to coordinate hand movements with eye movements to maximize the available visual information to properly guide hand movements and to reduce dependence on memory while performing complex aiming tasks.

In sports research over the past two decades, a consistent finding involving aiming proficiency has revealed that skilled and accurate performance is characterized by a specific visuomotor strategy, which has been termed the “quiet eye period” (Vickers, 1996). McPherson and Vickers (2004) described quiet eye as an “optimal focus on one location or object prior to the final execution of the skill”. In addition, quiet eye has been found to be important when anticipating the movement of objects in sports (Croft, Button, & Dicks, 2009; Davids, Renshaw, & Glazier, 2005; Fery & Crognier, 2001; Martell & Vickers, 2004; McPherson & Vickers, 2004; Panchuk & Vickers, 2006; Panchuk & Vickers, 2009; Rangnathan & Carlton, 2007; Vickers & Adolphe, 1997). Research suggests that the duration of optimum quiet eye depends on the specific demands involved in the task, with more difficult tasks requiring longer quiet eye periods.

However, the majority of these studies have been tested for static self-paced tasks where the positions of both the performer and the target are stationary (De Oliveira, Oudejans, & Beek, 2006). Jump shooting in basketball, which has been described as a dynamic far aiming task is also similar to the skill of shooting in hockey as there is full body motion throughout the shot process. Studies on jump shooting have shown that in late-viewing conditions (just prior to ball release) lasting between 350-450ms were sufficient for success when shooting and that basketball players prefer to pick up optical information as late as possible (Oudejans, van de Langenberg, & Hutter, 2002; De Oliveira et al., 2006). Athletes in open sports have to use their vision in order to identify relevant cues which help to predict what their opposing players will do, and also to calculate the future direction of the ball or puck. Previous studies in sports have shown that elite level athletes have different gaze strategies and characteristics than non-elite level athletes in their respective sports. Eye tracking studies have been performed on sports which range from table tennis to archery and also ice hockey, but not shooting in ice hockey (Behan and Wilson, 2008; Martell & Vickers, 2004; Rodrigues, Vickers, & Williams, 2002; Panchuk & Vickers, 2006; Panchuk & Vickers, 2009;).

Gaze characteristics as well as the duration of the quiet eye of an ice hockey player during the execution of a wrist shot must be analyzed to discover what visual cues an accurate shooter utilizes, and exactly what characteristics they have acquired that non-accurate shooters have not.

1.1 Nature and scope of the problem

The skill of shooting in ice hockey is a particular area where much more research must be conducted to increase our understanding. There are two outcomes that players wish to achieve when taking a shot in ice hockey; they want the puck to move with a high velocity, and they want the shot to be accurate. The study by Wu, Pearsall, Hodges, Turcotte, & Lefebvre (2003) showed that puck speed increases with skill level and hockey players of a high calibre manipulate the stick differently than lower calibre players. Michaud-Paquette, Pearsall, & Turcotte (2008) found that shooting accuracy in ice hockey appeared to depend on the amount of bend of the hockey stick during the shot, and that a more linear swing motion during contact leads to better guidance toward the intended target. These studies help to describe some of the mechanics of the body and stick during the shot that are important in allowing a shooter to be successful. Many more studies will need to be conducted to outline all significant attributes important for ice hockey shooting.

Joan Vickers has performed gaze research studies in ice hockey to determine player's gaze characteristics during defensive plays (Martell & Vickers, 2004) as well as goalie's gaze characteristics and duration of quiet eye while attempting to save a wrist shot (Panchuk & Vickers, 2006; Panchuk & Vickers, 2009). Martell and Vickers found that during defensive ice hockey tactics, elite players differ in their gaze control strategies compared to non-elite players. Panchuk and Vickers (2006, 2009) studies on ice hockey goaltenders found that elite goaltenders used visual cues, mainly from the stick, to predict where the puck would be directed.

One aspect that has not been evaluated extensively is the visual or gaze characteristics of ice hockey players during the performance of shooting tasks. Visual characteristics involved in the ice hockey shot include where the player is looking, how long the player is looking at this location, and when gaze changes are made during the course of the event of interest. To determine the visual characteristics an eye tracking device called the Model 501 Head Mounted Eye Tracker (Applied Science Laboratories, Bedford, MA) will be calibrated and worn by the subjects in a similar manner as has been used in other eye tracking studies.

The hockey shot consists of characteristics that are similar to other sport skills, but also has unique technical aspects. Not only are there different types of shots but there is also often a time frame in which release of the puck must be completed in order to achieve a successful result in a game situation. The fact that there is this time frame which causes players in ice hockey to release the shot at an extremely fast pace makes it difficult to measure quiet eye durations as previously defined. One requirement of quiet eye in the definition by Vickers (1996) is that “its onset occurs before the final movement common to all performers of the skill”. The final movement during a wrist shot in ice hockey is very difficult to identify because of the continuous sweeping motion through the shot. If the beginning of the sweeping motion was determined to be the onset of the final movement, than the quiet eye duration would often be 0.00s because the shooter typically begins to gaze at the target after the sweeping motion has been initiated. That is why in the present study quiet eye durations were not calculated. Instead the duration of gaze time on the target prior to the shot release was measured.

In the present study, a shooting protocol will be performed on a synthetic ice surface in a laboratory environment, allowing for more control of the experimental conditions. The synthetic ice has similar physical attributes to regular ice, but it has a higher coefficient of friction which is reported to be $\mu \approx 0.28$ by Viking® ice. Performing the protocol in the laboratory reduces the amount of time for set-up prior to data collection and since a large space is not needed, the synthetic ice is a more practical alternative for this type of data collection than real ice.

1.2 Rationale

Previous research involving sports and vision has revealed differences between elite athletes compared to non-elite athletes regarding gaze characteristics during the performance of skills. The gaze characteristics of a hockey player have yet to be examined. Many assumptions could be made about where a hockey player looks when shooting, but what is not known is the exact timing of gaze changes and the amount of time spent focusing on different areas of the player’s surroundings. By investigating these factors, it is possible to determine whether accurate ice hockey shooters differ in comparison to less accurate hockey shooters and the nature of these differences. The visual characteristics that the accurate shooting players exhibit, could be an important consideration in an effort to understand the skillful execution of a hockey shot that has to this point not been examined in this manner in the research literature. The skill of shooting is determined by a number of mechanical factors that work together. The extent to which each factor influences the resulting performance is not well known given the limited research specific to ice hockey (Pearsall et al., 2000). Understanding how players use visual information during skill execution is an important part of the description of a specific skill, and may help players to improve their shooting ability.

1.3 Objectives and hypotheses of proposed research

The objective of this study is to determine the different gaze characteristics between skilled (accurate) and unskilled (inaccurate) ice hockey players during the performance of a wrist shot in ice hockey. A differentiation will also be made on these characteristics with time pressure and no time pressure on the shooters. Examining the gaze characteristics an accurate shooter utilizes throughout shot execution will isolate important visual cues a player uses as well as the timing of those visual cues during both shooting conditions. Hypotheses related to this study are based on the literature review and are outlined below.

1. Gaze time on target prior to release of shot will be a longer duration :
   - for accurate shooters versus inaccurate shooters
   - for the self-paced shooting task versus the time pressure task

1.4 Limitations and delimitations of this study

Although this study strives to be both internally and externally valid, there are some limitations and delimitations associated with the research design, including:

1.4.1 Limitations:

- The experiments will be conducted under laboratory conditions with an artificial surface covered by lubricated polyethylene used to simulate ice conditions.
- The laboratory experiments were conducted at room temperature (22 to 24 °C).
- These experiments were not performed in a real game situation.
- The lens on Model 501 Eye Tracker only tracks left eye as there is only one lens.
- The eye-tracker is not able to record the full visual angle that a human is able to view, so when a subject glances outside the periphery that can be recorded it is not possible to determine where the shooters are looking.
- Subjects may shoot the puck with less force than they would in a game situation in an effort to improve their accuracy.

1.4.2 Delimitations:

- Only examined standing wrist shots f*rom 4 m at a 90° angl*e from the post that matched with their shooting side (i.e. left-handed shooter lined up stick blade with the left post from his view.
- Only male shooters in the 18 to 30 year old range were observed.
- The stick the subject used for shooting was their choice.

1.5 Operational definitions

Shot accuracy	Shot accuracy will be the determining factor of high or low calibre for group assignment post-hoc.
Shot release	Point in which puck has elevated off the ice during the wrist shot.
Forehand	Natural side on which a player will utilize his hockey stick; dominant hand is on the ipsilateral side of the body (e.g. right handed player will have lower right hand on right side of their body).
Backhand	When the hockey stick is used on the opposite side of what is natural for the player; the dominant hand will cross the player's body to the contralateral side (e.g. right handed player has lower right hand placed across their trunk on left side of body).
Wrist shot	The stick is used to draw the puck back with the posterior portion of the stick blade followed by a sweeping motion in the forward direction with the puck on the anterior portion of the blade, finishing with a 'snap' of the wrists.

1.6 Contribution to the field

Quantitative data for the duration of the focus for different gaze locations during a basic hockey wrist shot under different time constraints will allow us to understand how accurate shooter gaze techniques differ from that of less accurate players during the execution of wrist shots. By identifying visual cues important for successful (accurate) shooting, suggestions can be made to players of all skill levels for modifications of shooting techniques as it pertains to gaze characteristics.

Chapter 2: Review of literature

2.1 Vision physiology

Whether we know it or not we perform visual tasks and focus visually on different visual cues constantly. Throughout the day we move our head and eyes for the purpose of aligning the fovea with visual targets. The central fovea or fovea is a tiny area found in the centre of the macula lutea (Tortora, 2005). The macula lutea is located in the exact centre of the posterior section of the retina, at the visual axis of the eye (Tortora, 2005). The fovea is the region with the highest visual acuity or resolution (Tortora, 2005) and this is why we attempt to align it with objects on which we want to focus. The area that we are able to actually see clearly is only two to three degrees of visual angle, which is due to the small size of the fovea (Vickers, 2007). Visual information enters through the retina and passes through the optic tract to the thalamus and then via the optic radiation to the primary visual cortex (McDowell et al., 2008). The retina is the third and innermost lining of the eyeball. It covers the posterior three-quarters of the eyeball and marks the beginning of the visual pathway (Tortora, 2005). The neural layer of the retina thoroughly processes visual data and eventually sends nerve impulses into axons that form the optic nerve (Tortora, 2005). There are three distinct layers of retinal neurons which are the photoreceptor layer, the bipolar cell layer, and the ganglion cell layer (Tortora, 2005). They are separated by the outer and inner synaptic layers which is where synaptic contacts occur (Tortora, 2005). The ganglion cell's axons move to the posterior toward the optic disc and exit the eyeball as the optic nerve (Tortora, 2005).

The visual stimulus arrives in the primary visual cortex 100-120 ms after it is initially perceived (McDowell et al., 2008). From the primary visual cortex, information is relayed to extra striate cortical regions V2 and V3 (also part of the visual cortex) which are located in the middle of the occipital gyrus (McDowell, Dyckman, Austin, & Clementz, 2008). V2 and V3 are involved in mapping important stimuli in visual space and are most often activated by stimuli in the contra lateral visual field (McDowell et al., 2008). More than half the sensory receptors in the human body can be found in the eyes and a large portion of the cerebral cortex is devoted to processing visual information (Tortora, 2005).

2.2 Attention

Visually mediated actions rely on three systems: the gaze system responsible for locating and fixating task-relevant objects, the motor system of the limbs to carry out the task, and the visual system to supply information to the other two (Land, 2009). The difference between the gaze system and the visual system is that the gaze system is more physical such as the movement of the eyes, whereas the visual system consists of the actual visualization and interpretation of observed visual information. The gaze system consists of the frontal eye fields (FEFs) and the lateral intraparietal area of the parietal lobe (Land, 2009). These are reciprocally connected to the superior colliculus and eventually lead to the oculomotor nuclei of the brain stem (Land, 2009). The motor areas consist of the primary motor cortex, the premotor cortex, and various parietal areas involved with reaching and grasping (Land, 2009). The occipital lobe and much of the temporal lobe control the visual system (Land, 2009). Land believes that all three systems are under the control of a fourth system, the schema system, which specifies the current task and plans the overall sequence of actions (Land, 2009). Land suggests that the schema is the provider of the set of instructions for the performance of the next action in the task sequence, a set of instructions that determines where gaze will be directed, what information the visual system will be called upon to provide, and what action will be taken (Land, 2009). The region most associated with the schema system is the dorsolateral prefrontal cortex. Damage to this region does not affect the performance of individual actions but is detrimental to their organization (Land, 2009). Figure 2.1 is a demonstration of how the schema coordinates with the other systems as well as what brain regions are responsible for each system.

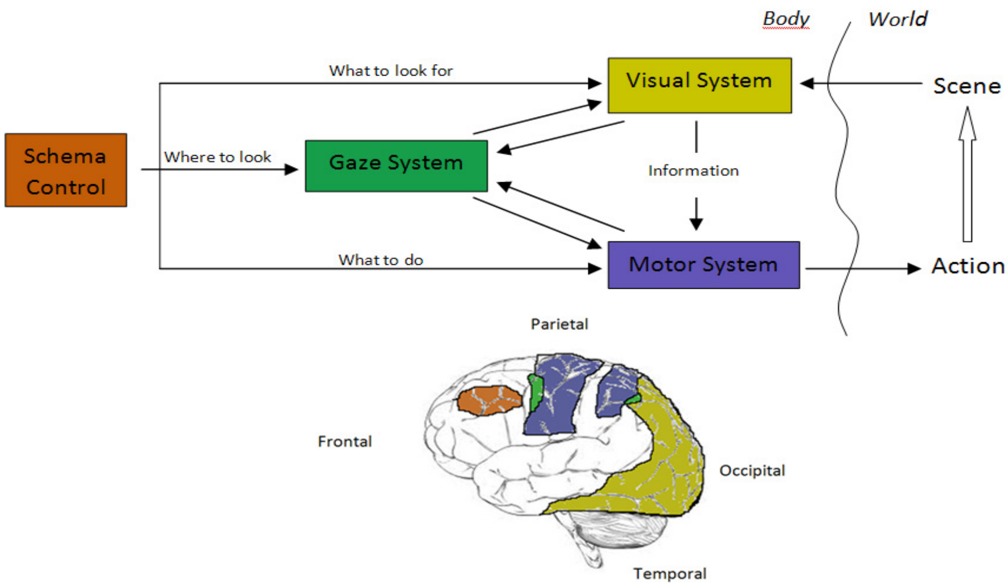

Figure 2.1: Representation of the relationship between schema control and the gaze system, visual system, and motor system. Image of brain illustrates what regions of the brain control the different systems (adapted from Land, 2009).

Several studies show that gaze and attention share the same neural structures of the brain and probably use similar neural mechanisms (McPherson & Vickers, 2004). The neural structures that are shared are the parietal cortex and frontal cortex which have been observed both with neuroimaging and electrophysiological methods

(Corbetta, 1998). Neuroimaging methods that have been used include positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) (Corbetta, 1998). These signals can be reasonably linked to some of the psychological effects described when subjects (human or monkeys) reflexively or voluntarily allocate attention to a visual location. Gaze is defined as "the absolute position of the eyes in space" (McPherson & Vickers, 2004). Corbetta (1998) defines attention as "the mental ability to select stimuli, responses, memories, or thoughts that are behaviourally relevant among the many others that are behaviourally irrelevant". McPherson and colleagues describe two types of attention: covert and overt. During overt attention both the gaze and locus of attention fall on the same area of interest, whereas with covert attention the gaze is located on one location and attention on another (McPherson & Vickers, 2004). Covert attention is often used in sport as a way to confuse an opponent. Between 60% and 80% of the activated regions are shared by the same areas in the frontal, parietal, and temporal lobes of the brain (McPherson & Vickers, 2004). Attention, when discussed with perception, has been defined by Findlay (2009) as "any process which allows certain aspects of the environment to be selected relative to the remainder".

Various objects in the surroundings may be attention-grabbing, which is termed exogenous direction of attention (Findlay, 2009). Endogenous attention takes place when internal processes encourage selection and there are at least three documented ways in which this occurs: selection by location, selection of objects and selection of features (Findlay, 2009).

The ability to direct attention towards a new visual event in the peripheral visual field, such as the onset of a new visual ‘target’, is a very basic visual function (Findlay, 2009). The saccadic eye movement system orients our eyes to match up with the target so it is focused within the central region of our field of vision which is up to about 12 degrees (Findlay, 2009).

2.3 Spatial attention and eye movements

Space is coded and transformed into action through a series of parieto-frontal circuits working in parallel (Craighero, Fadiga, Rizzolatti, & Umilta, 1999); however, the coordinate frame in which the space is encoded depends on the motor requirements of the effectors that the circuit controls (Rizzolatti, Riggio, & Sheliga, 1994). The parieto-frontal circuits consist of links between the parietal lobe’s cortical areas with areas of the frontal lobe which are the prefrontal cortex, premotor cortex, and the frontal eye fields (FEFs), which encode object locations in relation to a variety of reference frames (Colby & Goldberg, 1999).

The premotor theory defined by Rizzolatti et al. states, “spatial attention is a consequence of an activation of those cortical circuits and subcortical center that are involved in the transformation of spatial information into action” (Craighero et al., 1999).

Moreover, this theory assumes that there is a delay between the preparation of motor programs and action execution due to spatial attention (Craighero et al., 1999). Spatial attention causes an increase in motor readiness to act in the direction of the prepared motor program and allows for the facilitated processing of stimuli coming from that space sector (Craighero et al., 1999). Therefore, attention originates from the mechanisms that produce action, but is also influenced by the code space that programs eye movements (Craighero et al., 1999).

Research suggests that attention and eye movements interact, such that an oculomotor program is prepared every time attention is directed at a target (Craighero et al., 1999). Joan Vickers (2007) defines saccades as “rapid eye movements that bring the point of maximal visual acuity onto the fovea so that it can be seen with clarity”. In natural scanning, a series of saccades occur, taking the line of sight from one location to the next and so on (Gersch, Kowler, & Dosher, 2004). Humans usually make saccadic gaze shifts several times each second (Findlay, 2009).

Sheliga, Riggio, Craighero, & Rizzolatti (1995) showed that horizontal saccades can be modified by spatial attention, which also supports the view that spatial attention and eye movement programming share the same neural mechanisms. Although attention and ocular movements are closely linked during target-oriented visual search, the same may not be true for exploratory eye movements (Craighero et al., 1999). For example, studies have shown that cortical areas including frontal eye fields become active during target-directed eye movements but not during spontaneous saccades (Craighero et al., 1999). Therefore, the research suggests that positioning the fovea on a special location will allow for extraction of relevant information during target directed eye movements (Craighero et al., 1999).

A selective attention filter is essential to have the eyes focus on important objects within visually crowded environments (Gersch et al., 2004). This helps to ensure that the saccade is directed accurately to the central target rather than to surrounding irrelevant objects (Gersch et al., 2004).

The study by Gersch et al. (2004) examined the relationship between attention and sequences of saccades, rather than single eye movements. They felt that saccades performed as part of a sequence would require different attention demands than a single saccade. Gersch et al. investigated this issue by using a visual task to evaluate how attention was allocated over space and time when the subject was performing simple saccadic sequences. The results showed a beneficial effect for visual performance when there was a shift of attention to the target of the saccade. Overall they found that during inter-saccadic intervals, attention was allocated largely to the current fixation location and to the target of the next saccade but not for subsequent saccades.

In addition to linking spatial attention to eye movements, the premotor theory also maintains that attention is related to objects (Craighero et al., 1999). The objects are processed in two major corticocortical processing pathways, or streams, each of which begins with the primary visual cortex, or VI. One called the ventral stream, is directed into the inferior temporal cortex and is important for object recognition, while the other, the dorsal stream, is directed into the posterior parietal cortex and is important for spatial perception and visuomotor performance (Desimone & Duncan, 1995).

Furthermore, research has shown that the sight of an object will automatically increase motor readiness to execute the appropriate movement (Craighero et al., 1999). Consequently, the premotor theory of attention can also be generalized to the attention of an object that will be acted upon (Craighero et al., 1999).

A study by Fehd & Sieffert (2008) attempted to determine where subjects looked while tracking multiple objects. Visual stimuli consisted of 8 red dots within a white square frame on a black background presented on a computer monitor 38.5 cm away from the subjects. Starting at the onset of the dot array, green rings representing the targets appeared on either 1 or 3 of the dots for 3 s after which participants selected each target with the mouse. Their results suggested that when multiple objects are tracked, more time is spent looking towards the centre of the target array than at each target individually. This seems to be a result of grouping the targets into a single object (Fehd & Seiffert, 2008).

The purpose of a study by Schubo and Muller (2009) was to investigate the effect of top-down (goal oriented) control on bottom-up (rapid and automatic) singleton processing during visual search tasks. In bottom-up processing the subject is attempting to select an object that differs from the others based on some visual contrast that isolates this object from the remaining surrounding objects. In the top-down process the subject has some expectation about the pattern of the target he will be looking for. A singleton is a single target which is surrounded by similar objects but differs in some minor detail such as colour. The results suggested that it is much more difficult to ignore a previously relevant singleton, compared to singletons without previous task relevance. The top-down process almost completely prevented the selection of objects which are not important, but when non-target objects are found in the same dimension as the target, it becomes much more complicated for the subject to distinguish between the two objects.

The top-down process is an example of how visual short term memory can preactivate the brain and leads to attention bias toward an object. Literature related to vision has shown that visual short term memory can have an effect on attention. Olivers (2010) wanted to determine the role of long term memory related to attention. The subjects in this experiment were asked to search for the shape of a common traffic sign in a black and white display of several signs while the distracter signs were the only ones presented in colour. The authors suggested that interference by an associated colour could possibly mean that irrelevant but related visual attributes automatically guide attention. Reaction Times (RTs) were 37 ms slower when the distracter colour was related to the target (1020 ms) than when it was unrelated (983 ms). The results showed strong support for attention interference based on long-term visual representations. Olivers (2010) concluded that when observers are searching for a well-known object, they do not only pick up the property that is important to the task, but their attention triggers automatically to other visual properties strongly linked to that object.

Wolfe, Palmer, & Horowitze (2009) wanted to look at the simple visual tasks that are often found in visual search literature and measure and compare their mean RT distributions with different set sizes. They collected 1000 trials from 9 or 10 subjects at each of four set sizes for three of the most popular laboratory search tasks. Task 1 tested participants on a simple feature search for a red vertical rectangle among seven green vertical rectangles. Task 2 was a conjunction search task for a red vertical rectangle among green vertical and red horizontal rectangles. In task 3 which was a spatial configuration search, observers searched for a digital “2” among digital “5”s. In feature search, colour guides attention to the target almost right away every time and distracters get little or no attention (Wolfe et al., 2009). In spatial configuration search, no basic attribute guides the subject’s attention so they must seek the entire display (Wolfe et al., 2009). In conjunction search, no single feature can direct attention straight to the target but the combination of relevant colour and orientation can help guide the subject toward the target item (Wolfe et al., 2009). The results showed that feature search required the shortest mean RT, followed by conjunction search, and spatial configuration search had the highest mean RT. For feature and conjunction search, the normalized distributions for present and absent trials are very similar. Under most conditions, set size had no clear impact on the RTs.

A simple visual scanning study by Philips & Edelman (2007) aimed to understand the variability of performance and the affects of learning in a saccadic visual search task. The study involved simple visual tasks on a screen and the subject's gaze was recorded using an eye tracking system. Two to four sessions were performed each week over the course of three weeks to determine if any substantial changes occurred in search speed, fixation duration, or saccade amplitude. They defined search speed as "search time divided by the number of items from the beginning of the list to the target, inclusive". By the end of the study, the authors had found that search speed improved significantly in all subjects. The improvement in performance (search speed) by the end of the study correlated strongly with an increased number of items scanned per fixation (mean $r = .92$) and increased amplitude of saccades (mean $r = .50$).

Research has shown that novices benefit from additional attention to the execution of the motor task, but when experts spend too much time focusing on the already automated task this negatively affects their performance (Memmert, Simons, & Grimme, 2009). The central goal of the study by Memmert et al. (2009) was to examine differences in the basic attention abilities of team sports athletes to see whether they are better than the average non-athlete on attention tasks or whether their attention advantages might be limited to their domain of expertise. There were three groups of participants made up of both men and women. One group was made up of athletes with 10 years experience or more in handball, another group with the same level of experience but in non-team sports, and the final group was made up of non athletes. They found that experts were no better than novices at dividing their attention between the focus of fixation and other areas of the scene. Performance on a multiple-object tracking task was comparable across groups, with no differences between team sport experts and other groups. This finding is inconsistent with evidence for enhanced focus of attention in expert athletes but is consistent with evidence that athletes are no better than non-athletes at basic vision perceptual tasks.

2.4 Anticipation

Researchers to this point on eye tracking in sport have used two methods for their research; the visual search paradigm, where the athlete's eye movements are recorded as they view scenes from their sport, and live protocols where the gaze is recorded in the action setting (McPherson and Vickers, 2004). With a visual search paradigm, the athlete looks at pictures, slides, videotapes, or other displays for information shown under different temporal constraints (McPherson & Vickers, 2004). When the gaze is recorded in the live setting, which is similar to a game situation, the immense amount of information surrounding the subject is ignored in favour of fixations or tracking gaze to specific locations (McPherson & Vickers, 2004).

While the athletes use their vision to identify cues, they must still process this information to eventually make a decision and act on what they are predicting. There are two schools of thought regarding how athletes process this information when performing an interceptive task. Predictive control represents an approach in which actions are planned entirely before their execution (Panchuk and Vickers, 2009). In predictive strategies, the current state of the subject and his environment helps to predict a future event, such as an object arriving at a particular point at a particular time (Dessing, Bullock, Peper, & Beek, 2002). This approach seems to be more applicable in extremely fast moving sports or skills where the brain is not able to function fast enough to make sudden changes.

The other school of thought is prospective control where significant moving objects and the actions of the subject are continuously updated to the point of interception (Panchuk & Vickers, 2009). Prospective control leads to a more accurate perception-action coupling than predictive control, because successful prospective control is not critically dependent on the accuracy of a single, instantaneous perception (Dessing et al., 2002). Prospective control is much more precise when the object being intercepted is moving at a pace that allows the eyes to track it.

Research suggests that combinations of predictive and prospective control strategies are used to help with interceptive timing movements (Panchuk & Vickers, 2009). The continuously changing environment may limit the accuracy of the predictions on which the programming of such actions is based, particularly when the time between prediction and interception is long (Dessing et al., 2002). To remedy this shortcoming, it has been suggested that pre-programmed actions could be supplemented by on-line adjustments based on updated predictions (Dessing et al., 2002).

Panchuk and Vickers (2009) wanted to determine how four different occluded conditions would affect the performance of eight elite male varsity goaltenders and whether their coupled gaze and motor behaviours would change across conditions. A mobile eye tracking system was worn by the goaltenders and an external video was used to show an image of the goalie's movements. Overall, the results suggested that goaltenders used a predictive control strategy in which early vision of the puck and stick contributed to a higher percentage of saves. In addition, poorer performance was found when more of the shooter's actions were not visible and they had a slower reaction time when all but puck flight was occluded. This data provides support for the notion that prediction was crucial for success in goaltenders. However, on 22.8% of 79 glove saves sampled for high speed analysis, movement reversals were found during puck flight which may indicate that some prospective control occurred. No glove or gaze adjustments were seen during the final 125 ms of puck flight, which may be a sign that prospective control is not possible beyond this point.

Using visual cues in sports to predict events in the subsequent few milliseconds to seconds after the beginning of an event can be very beneficial to individual players and teams. Ice hockey is an open sport where the ability to quickly read offensive and defensive play patterns is critical (Martell & Vickers, 2004). In open sports the ability to quickly give meaning to a limited number of relevant resources seems to allow faster and better anticipation of the opponent's intended actions (Fery & Crognier, 2001). In a study by Fery & Crognier (2001), expert tennis players watched tennis matches and blocked the observer's vision 100 ms after the stroke. The results showed that the important anticipative information was viewing the opponent's stroke movements and the first part of the ball movement to predict the final location of the ball.

With interceptive timing skills or externally-paced tasks, different gaze behaviours are used depending on the predictability of flight of the object. When the object's flight is predictable, there is an early onset of pursuit tracking, followed by a long duration of tracking the ball, which rarely occurs to contact (McPherson & Vickers, 2004). Smooth pursuit eye movements allow humans to use detailed, continuous information about a moving object (Croft et al., 2009). Pursuit tracking is the slow rotation of the eyeballs following the tracked object. Humans are normally able to track a moving target at a speed of 1-100 degrees/s (Croft et al., 2009). However, in fast ball sports, pursuit tracking is often too slow, especially when the target is moving at its highest velocities. Fast approaching objects require early onset of tracking followed by an anticipatory saccade, and a later short period of tracking before the ball or puck is contacted (Croft et al., 2009).

In a cricket batting study performed by Davids et al. (2005), their results showed that the removal of predictive information changed the timing of batters' movements. Croft et al. (2009) performed a study with sub-elite to elite cricket batsmen to look at the gaze behaviours of the athletes during differing speeds of pitches. The gaze strategies used varied considerably even within participants from complete pursuit tracking, to a combination of pursuit and saccades, and also a new strategy called parafoveal tracking. Parafoveal tracking involves pursuit tracking, but also gaining details and information from areas surrounding the visual target that are not directly fixated on by the fovea. They found that skilled batsmen need to modify their gaze behaviour on every pitch in order to play a successful shot.

Ranganathan and Carlton (2007) showed that baseball batters coupled the start and duration of their step to the kinematics of the pitcher while using ball flight information to control swing speed.

Panchuk and Vickers (2006) performed another goaltending study in ice hockey where no occlusion occurred but the main concern was to reveal where the goalies focused with their eyes prior to a wrist shot taken from 5m and 10m away. Reaction time (RT) was significantly less in the 5m shot, but both were well under the visual reaction time threshold which is about 180-200ms for novel tasks. These short RT's provide evidence that goalies use predictive information to anticipate the direction of the shots. The primary fixation/tracking location was the puck on the stick as the wrist shot was prepared and executed (70.53%), followed by the ice in front of the stick (25.68%).

Vickers and Adolphe (1997) compared the gaze of elite Team Canada volleyball players to that of near-elite receivers on the same team. A training study was later carried out where the players were trained to initiate tracking sooner and maintain their gaze longer on the ball before the pass was made. The training was successful in significantly improving the onset and duration of quiet eye tracking during the experimental setting, and a three-year follow-up showed that the accuracy of the trained group significantly improved compared to top world receivers.

A gaze study performed by McPherson and Vickers (2004) had tracked the gaze behaviour's of five junior male volleyball players two of which were members of Team Canada while three were trying out for that team. The highest percentage of all gaze were directed to the ball (62%), followed by the parked gaze in front (20%), the server's head (14%), and the serve anticipation point (4%). No gaze behaviours were directed to the target area, nor were any other gaze locations found. During the serve, three locations were fixated or tracked, on the ball (55%), the server's head (35%), and the serve AP (11%). During the flight phase, tracking on the ball accounted for 66% of the fixations or tracking and the parked gaze in front for 34%. They found that subject 4 had the lowest level of accuracy and they suggested this was due to the fact that he initiated tracking very late and then tried to maintain tracking on the ball till contact.

In closed skills, the primary object of interest does not move, which results in a stable gaze being used due to the unchanging nature of the object, while in open skills a more complex type of gaze control would be required due to the search for objects within the evolving environment (Martell & Vickers, 2004). Studies of gaze control in sports have shown that elite players are faster than non-elite in making decisions and that these decisions are of higher quality (Martell & Vickers, 2004). A study by Martell and Vickers (2004) on ice hockey defensive tactics focused on the temporal regulation of their gaze, specifically the onset and duration of fixation and tracking. The study compared elite vs. non-elite players and the data showed that both sets of players used two different gaze control strategies. They began by fixating or tracking specific locations for short durations at the beginning of the play, and concluded with a final gaze for a long period to a relatively stable target at the end. It was also found that the elite group fixated the different locations more rapidly than the non-elite on successful plays.

2.5 Aiming

In most sports athletes have a target at which they attempt to place a projectile such as a ball, a bullet, a javelin or a puck. Whether it is an open-skilled sport like hockey or a closed-skilled sport like biathlon, it is always the athlete's goal to hit the target consistently. The biggest difference is that, often in open-skilled sports there is a member of the opposition trying to block the target or a path to the target which ultimately limits the trajectory that a given projectile can follow to reach those desired targets. Thus, aiming appropriately at targets is crucial for success in most sports. When performing complex aiming tasks also known as self-paced tasks, humans appear to coordinate hand movements with eye movements to maximize the available visual information to appropriately guide hand movements and to minimize reliance on memory (Brouwer & Knill, 2007). If in a given set of conditions, vision is significantly more reliable than the information stored in memory, vision will dominate, but in conditions where vision information is impaired or limited in some manner, the brain will retrieve memory information from higher CNS levels to plan movements (Brouwer & Knill, 2007).

Brouwer and Knill (2007) found that subjects relied more on memory for objects where there was less visual contrast, which is consistent with the prediction that decreasing the reliability of visual information leads to an increased reliance on other sources of information. Their experiment showed that unconscious memory is used not only for gaze and attention but also for planning hand movements, even with simultaneous availability of peripheral visual information (Brouwer & Knill, 2007).

Helsen, Elliot, Starkes, & Ricker (2000) examined initiation latencies as well as the kinematics of hand, elbow and shoulder movements in a goal-directed aiming task. The eyes moved first on the majority of trials and the mean latency difference between the eyes and the hand was 21ms. The three limb segments showed a proximal-to-distal order of movement initiation. In every case, the eyes were at rest over the target much earlier than when the hand moved into the target area. This seemed to occur in an effort to have the eyes positioned optimally. This made it easier to recognize important visual information regarding the relative position of the hand and the target during the final portion of the limb movement (Helsen et al., 2000).

Anytime we are looking for an object or a target the orientation and position of the head strongly affects the visual field (Kim, Gillespie, & Martin, 2007). Head mobility has the ability to move + or – 64 degrees when rotating horizontally (Kim et al., 2007). This can be used to improve the field of view beyond the mechanical range of motion (ROM) for the eyes which is + or – 55 degrees for horizontal rotation (Kim et al., 2007). Combining the ROM of the eyes with head mobility results in an effective gaze range that covers approximately + or – 119 degrees of a person's surroundings (Kim et al., 2007). The average functional range of motion (ROM) of the eyes, has been defined as "the region within which the eyes are directed with a frequency of 90% for all head orientations," is + or – 22 degrees (Kim et al., 2007). Since head movements are vital for placing targets of large eccentricity into our field of vision, accurate information about these targets may not be available until a movement is initiated (Kim et al., 2007).

Kim et al. (2007) used two experiments to determine how head movements were performed during visually guided head and finger aiming tasks. One experiment constrained the head and in a second experiment the head was unconstrained. The results suggested that head movement kinematics involve an abbreviated fast component followed by multiple corrections. When the target is within foveal vision, its location can be estimated and corrective movements are used to place the head in the best location based on proprioceptive feedback. The authors suggest that head movements, particularly in unconstrained conditions, go through a process involving a number of kinematic variations using a loosely programmed on-the-fly strategy.

In a study by Henriques and Crawford (2002), the objective was to determine whether placement of the head in different horizontal positions during pointing tasks would affect their accuracy due to an alteration of their visual situation. The results showed that subjects were able to re-calculate their positions and accurately place their finger on the target regardless of their head position.

A consistent finding from research involving aiming proficiency is that skilled and accurate performance is characterized by a specific visuomotor strategy, which has been termed the “quiet eye period” (Vickers, 1996). The quiet eye is a term that has been used very frequently in the literature over the past couple of decades with regard to anticipating or aiming in sport.

The quiet eye has four characteristics: it is directed to a critical location or object in the performance space; its onset occurs before the final movement common to all performers of the skill; its duration tends to be longer for elite performers; and it is stable and does not deviate off target by more than 3 degrees of visual angle for more than 100 ms, confirming the need for an optimal focus on one location or object prior to the final execution of the skill (McPherson and Vickers, 2004). The duration of optimum quiet eye has been shown to depend on the specific demands of the task adopted, with more difficult tasks requiring longer quiet eye periods. However, an overly long quiet eye will not necessarily result in success (Behan & Wilson, 2008). Behan & Wilson (2008) described the quiet eye period as reflecting the organization of visual attention control parameters for the movement. In particular, longer quiet eye periods improve performance by allowing individuals to extend the time of cognitive programming required for accurate aiming movements (Behan & Wilson, 2008).

In a table tennis study by Rodrigues et al. (2002), the main aim of the study was to determine how players coordinate head, eye and arm movements to acquire the important visual information for successful performance on a table tennis task. Their target was cued by a set of lights either before the serve, early in the ball flight, or late in the ball flight. As previous literature suggests, participants kept their eyes on the ball early in flight but not during the final portion of its trajectory. High skill players were able to acquire the initial visual information faster and started their downward saccade towards the bounce area earlier. Quiet eye onset was delayed for the low skill group during misses compared to hits. A significant decline in performance accuracy was observed in the late-cue condition (mean=30%) compared with the pre- and early-cue conditions (combined mean=48%). Quiet eye onset was similar in the pre- and early-cue conditions but occurred significantly earlier in the late-cue condition, implying that the participants tried to acquire information as early as possible to provide time to detect the cue light. As the arm moved towards the ball, eye-head stabilization was initiated, which lasted for about 100 ms, up until a point 30 ms before ball-bat contact (Rodrigues et al., 2002). This is an example of how targets' changing makes the task of aiming much more difficult.

Although limited in amount, recent research has demonstrated that when anxious, performers tend to exhibit less efficient visual search behaviours (Behan & Wilson, 2008).

Vickers & Williams (2007) performed a study related to aiming; the researchers looked at how pressure affected biathlon athletes shooting skills, and also made them perform at power output (PO) levels of 55%, 70%, 85%, and 100% of their maximum oxygen uptake to see if this caused any changes in performance as well. In the low-pressure (LP) condition, the athletes were told the purpose was to observe their fixations on the target at different PO levels. In the high pressure (HP) condition, the national team coach was present and he told the athletes that he would use their shooting percentages for the national team selection. Three of the ten athletes were able to overcome all of the pressures by increasing their quiet eye duration to levels that differed significantly from those of the group that were less successful. Only three athletes were successful in overcoming all pressures presented as they missed the fewest targets during the HP condition and the athletes maintained 80% accuracy at HP PO100%. In comparison the other seven shooters shot at ≤ 40% accuracy at HP PO 100%. Those who performed well began with a low duration of quiet eye fixation during the LP condition and raised it as the pressures increased and this led to the greatest amount of success.

Behan and Wilson (2008) examined how individuals direct their gaze to obtain significant visual information for accurate performance on a computer simulated archery task and also how quiet eye is affected when pressure is added to the task. The quiet eye duration for accurate shots was 63% of the alignment phase of movement, whereas quiet eye durations of 50% were typically observed during inaccurate shots. The results indicate that an optimal duration of quiet eye is likely to exist for successful performance in self-paced aiming tasks. Quiet eye periods in this study and in the Janelle et al. (2000) study of rifle shooters ranged from 5 to 15 s, whereas in the basketball free throw shooting (Vickers, 1996) and billiards (Williams, Janelle, & Davids, 2002) quiet eye durations were approximately half a second to a full second. In the low pressure session final target fixations were for 62 % but in the high pressure session it reduced to 50 %. The quiet eye durations for misses were similar to those for the high anxiety condition, suggesting that the alteration in visual orientation, caused by increased anxiety, may have led to poorer performance.

The free throw in basketball is a complex targeting skill which involves the integration of visual information obtained through overt shifts of gaze with effector movements that carry out the aiming actions (Vickers, 1996). During a jump shot the body is in full motion and the distance to the target is often the shots are not taken from the same position (Oudejans et al., 2002). These descriptions are very similar to a shot in ice hockey; players use the visual information about the target and carry out aiming movements with their limbs to complete the task. In addition, their bodies are in full motion throughout the shot, and the position they take their shot from changes on a shot to shot basis.

In a basketball free throw study by Vickers (1996), a longer duration of quiet eye for the expert group combined with an early mean fixation offset during the shot phase were the most important findings distinguishing them from near-expert players. Vickers defined quiet eye duration in this study as the onset of the final fixation maintained until the first observable movement of the hands into the shooting action. Expert (E) quiet eye duration was 972 ms on hits and 806 ms on misses, compared to near-expert (NE), which had a quiet eye lasting 357 ms on hits and 393 ms on misses. Figure 2.2 displays the mean duration of quiet eye for expert compared to near-expert on hits versus misses. The authors suggested that during the preparation phase, a fixation of long duration is needed to adequately set the parameters of the shot, such as the location and distance to the target, the trajectory of the ball, the optimal forces needed throughout the action, the timing, and the coordination of the limbs. All of the NE athletes had a lot of head movement and other extraneous movements during the 2 s prior to the movement being initiated. E and NE differed significantly in the frequency and duration of gaze shifts because of head movement during the preparation. Subsequently, these athletes fixated the target for a brief quiet eye duration (M = 375 ms), which could suggest it is too short to optimally organize the neural structures underlying this complex movement (Vickers, 1996). Frequency of head movements for E was lower ($M =$ 0.64, $SD =$ 0.61) than for NE (M = 1.5, SD = 0.88), as was E duration ($M =$ 190 ms, $SD =$ 231) and NE duration (M = 454 ms, SD = 291). They also found differences during the shot phase, as E frequency of head movement was higher ($M =$ 0.97, $SD =$ 0.26) than the NE ($M =$ 0.74, SD = 0.44). During the shot phase, duration of head movement did not differ by skill level, accuracy, or trials for E, $M =$ 264 ms, $SD =$ 135, and NE, $M =$ 204 ms, $SD =$ 153.

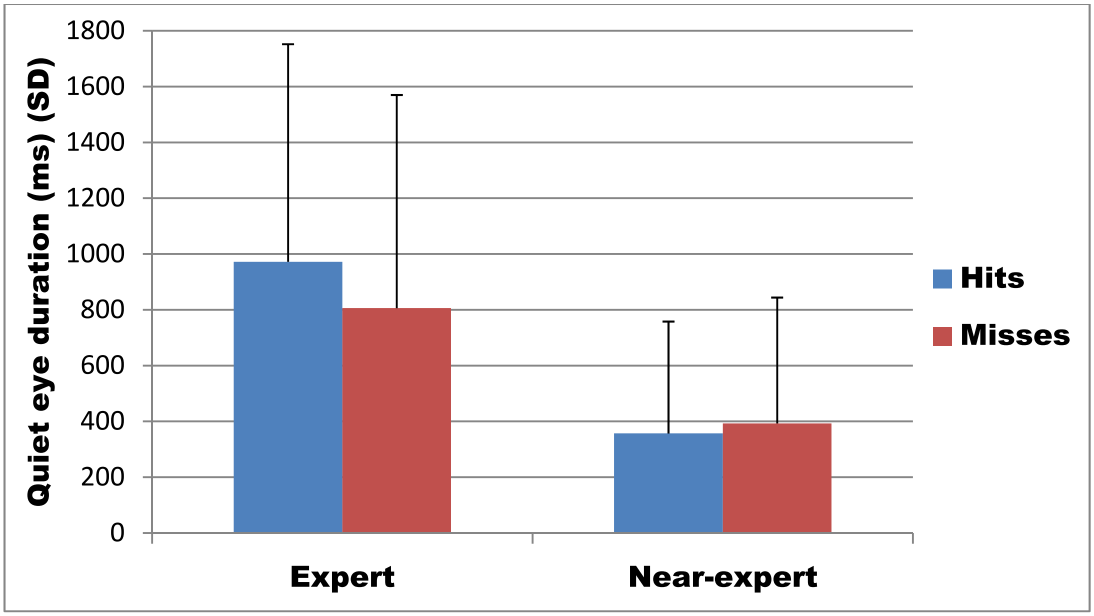

Figure 2.2: Mean duration of quiet eye for expert basketball players compared to near-expert players for hit versus missed free-throw shots (adapted from Vickers, 1996).

Contrary to a free throw, with jump shooting there is often not enough time for long fixations which results in less time for movement programming (De Oliveira et al., 2006). Also, for each jump shot the target is viewed from a different position, whereas with a free throw the target is always viewed identically. Timing of optical information pick-up can be crucial because the opportunities for information pick-up are restricted and the perceived information has to be used to control a dynamic movement where there will be neuromuscular delays (De Oliveira et al., 2006). Shooters are forced to acquire key information at the appropriate time when the information is perceptually available and can be used to guide the action (De Oliveira et al., 2006).

In a study by Oudejans et al. (2002) they investigated the relation between visual attention and motor control in basketball jump shooting by experts. They investigated the effect of early and late viewing of the hoop on basketball jump shooting with the high style. Oudejans and colleagues wanted to compare their results to Vickers (1996) study where the shooters were low style shooters. The low shooting style starts with the ball and hands below eye level and during the process of the shot the elbows extend, after which they move in front of the face (De Oliveira et al., 2006). With the high style, the ball is initially carried to a position above the head followed by an extension of the elbow until the ball is released (De Oliveira et al., 2006). Vision was temporally occluded during shooting using Plato Liquid Crystal (LC) goggles. It was hypothesized that high style late viewing, rather than early viewing, would allow for more precise final error corrections during the shooting movements. Shooting percentages with late vision only (M = 60.5%, SD = 12.9) were just as high as those with full vision (M = 61.5%, SD = 7.4), while with early-vision (M = 30.0%, SD = 16.4) performance deteriorated. In comparison to what the findings of Vickers (1996) showed for players with a low shooting style, having early vision did not result in good performance for the high style shooters in this study. Oudejans et al. concluded based on their results that continual processing of visual information must have been crucial for late-vision shooting with the high style.

De Oliveira et al. (2006) used an identical experimental set-up to Oudejans et al. (2002) but tested both high style and low style shooters to find what time frame during the shot they preferred for viewing the basket. For the low-style group Line of sight (mLoS) towards the basket occurred just before the closing of the glasses, permitting vision just before ball and hands occluded the target, whereas in the high-style group mLoS occurred after the opening of the glasses, allowing mLoS until ball release. The shooting percentages found under intermittent late viewing were similar to those completed with full vision for both groups, which suggests that subjects were still able to pick up the crucial optical information about the target which allowed for successful shooting. They found that both groups of basketball jump shooters preferred to pick up optical information about the basket as late as possible. This moment in time for low style shooters is just before the basket is occluded by the ball and hands, and for high style shooters it is just before ball release.

2.6 Skill acquistion

In executing a motor task, the learner has to prevent the overload of information with irrelevant details that will hinder skill execution (Govatos, 1967). Motor skill learning involves execution of a series of movements in sequence, which is why a successful performance is dependent on the information feedback received after each sequence is completed (Govatos, 1967).

Early research by Poulton (1966) provided some interesting results on tracking tasks. Poulton suggested that the complexity of a tracking task is dependent on the load placed on the information capacity of the learner. When learning a skill during a tracking task, the learner must utilize information from his own proprioceptive system as well as information from his surroundings which leads to additional strain being placed on his information utilization system (Poulton, 1966). As a learner progresses with a skill they start to develop repeatable patterns, and this reduces the overall load on the information processing system (Poulton, 1966). Although this research was performed many years ago, the general ideas provided still hold today.

The precise role of feedback during skill acquisition is still unclear. The research literature seems to support the idea that performers rely on a specific source of feedback with practice, but it is still not known whether this reliance increases as the amount of practice increases (Krigolson & Tremblay, 2009). The goal of the study by Krigolson & Tremblay (2009) was to determine the validity of this notion. Eighty participants completed 10, 50, 100, or 200 acquisition trials in either a full-vision (FV) or no-vision (NV) and the task was throwing a bean bag three metres to a marked target. The results suggested that visual feedback was not important initially for the development of a movement pattern for the task at hand. But the data did show that there was an increased reliance on specific sources of afferent feedback after a large amount of practice (Krigolson & Tremblay, 2009). Thus, as the amount of practice increased the subjects began to use more relevant cues in their surroundings to improve their performance.

Vision not only allows people to be aware of their surroundings and plan future movements, but it is also important for balance while stationary or in movement. Paillard & Noe (2006) performed a study which compared the postural abilities of soccer players at different levels of competition under two different conditions: eyes open (EO) and eyes closed (EC). The results showed that amateur soccer players had a stronger dependence on vision for postural balance than professional soccer players. Since the professional players rely less on vision for postural control this may be an illustration of the acquisition of this ability to control the ball without watching it (Paillard & Noe, 2006).

Walking is often thought of as an automatic skill that is fairly consistent, but when an obstacle is in our path we must alter our walking pattern. Vision allows us to be aware of our environment, and allows us to modify our gait patterns by performing appropriate adjustments in body orientation in the case of obstructions in our walking path (Paquette & Vallis, 2010). These gait modifications are called anticipatory locomotor adjustments (ALAs) which involves altering foot placement, changing limb position in space or a combination of both (Paquette & Vallis, 2010).

To test the differences between older adults (OA) and younger adults (YA) walking characteristics, Paquette & Vallis (2010) performed a study to examine body and gaze reorientation strategies when only given one stride to prepare for an obstacle. The authors hypothesized that the older adults would focus on the landing point after the obstacle to ensure a safe landing with their lead foot. This strategy appeared true for both groups as they both focused their gaze on this area as they reached the obstacle. The authors found it interesting that no head yaw movements were found in OA. They felt this could have been due to the fact that the OA found it easier to navigate their surrounding environment with less head movement. Although no major differences were found in visual strategies for avoiding the obstacle, the authors did find that OA spent more time focusing their gaze on the ground during their two steps approaching the obstacle than YA.

In a soccer study which was performed by Janelle, Champenoy, Coombes, & Mousseau (2003), the purpose was to determine the optimal means of observational learning in an effort to learn the skill of a soccer pass. There were several groups which were all given a different learning method and each went through a practice phase, an acquisition phase, and a retention phase. They found that the group that watched a video model and were verbally and visually directed towards critical aspects of the task were more capable of creating an ideal kicking form that led to enhanced outcome scores compared with the participants in the other learning modalities (Janelle et al., 2003).

Studies concerning the effects of vision and kinaesthesia on golf-ball putting have shown that beginning golfers learn putting better when they use no visual cues (Fery & Ponserre, 2001). The idea was that a golf video game could be used as a modeling task, but only if the player used the modeling with the intent of making improvements in their actual putting skill. Sixty two right handed males with no prior golf experience made up the group of subjects for this study. The results suggested that when the beginner putters focused on amplitude and timing of the right to left movement of the gauge on the screen they performed better than the subjects who focused on the virtual players bodies on the screen during the post-test putting. Both of these groups performed better than the third group who only played for enjoyment (Fery & Ponserre, 2001).

A study by Hung, Kaminski, Fineman, Monroe, & Gentile (2008) with novice Frisbee throwers supports the notion that skill learning consists of two distinct processes that occur at different rates; the movement’s topology is acquired early in the process of skill development while refinements in dynamic control also occur but more slowly. They found that throwing accuracy rapidly improved early in practice and smaller changes or minor modifications occurred as the practice continued. Variability of each individual thrower’s kinematics also decreased after each practice session.

A study by Minkoff (1982) was one of the earliest studies involving sports and vision. Minkoff evaluated a championship professional hockey team based on specific evaluation of the visual system as well as the cardiovascular and muscular systems. Two aims of the paper were to establish cardiovascular, visual, and/or muscular tests with specificity to ice hockey, and to establish criteria to follow and to identify characteristics for future prospects based on those tests. For the visual testing each member of the team was subjected to several visual acuity tests. Each test had a scoring scale. A total eye score rating was based on the combined scores of the tests performed. Minkoff found that total eye score related strongly to shot accuracy but of the single tests only visual span had a significant correlation to shot accuracy. The third noteworthy correlation was that of vision span to success in face-offs. Of all 21 players tested, only six received the maximum score in either speed or span. Three were goalies and the other three were all-stars. Only three players scored a maximum in both speed and span: two were goalies and the third was the team's leading goal and point scorer for that season. The test for visual speed has the player look straight ahead and visually records numbers or words rapidly as they flash across a screen. Span incorporates peripheral vision by performing a similar test and spreading the visual targets farther and farther apart (Minkoff, 1982).

Studies of visual behaviour in sport were examined by Abernathy and Russell (1987) and Goulet, Bard, & Fleury (1989). These authors compared the ability of players, of different levels of expertise, to identify different filmed tennis and badminton service situations while their visual search activity was being monitored. Results showed no substantial difference related to players' expertise in visual search activity. Visual search activity consisted of allocating fixations to display regions, search order, search rate, and search organization. The authors found that considerable differences in response accuracy were noticeable. They came to the conclusion that the limiting factor in perceptual performance was being able to detect and use visual cues at important fixation locations.

The purpose of a study by Abernathy and Neal (1999) was to determine whether skilled clay target shooters had superior general visual skills in comparison to novice clay shooters. Contrary to prior assumptions and findings, they found little disparity in the visual dexterity between the groups. The only significant visual advantage the skilled shooters had over the novices was simple reaction time but the authors were quick to note that little weight should be placed on their finding for reaction time. They concluded from their data that it is reasonable to say that skilled clay target shooters are not characterized by superior vision, at least measured using generic tests. They believed that an advantage for skilled performers would only be seen if they tested in a functional way, using sport-specific stimuli. They also felt that these results contradict the use of generalized visual training programs as those programs aim to improve general visual skills which appear to not be an advantage for athletes.

In recent years, researchers have attempted to determine the methods behind information “pick up” in sport and mainly how these are controlled by several factors including the skill level of the performer, the nature of the task, and the emotional responses to various stressors (Williams et al., 2004). Many cognitive systems are involved in gaze tasks including short-term memory for previously attended information in the current scene, long-term memory of other similar scenes, and the goals and intentions of the viewer (Williams et al., 2004). Evidence of this can be seen from most sports studies where skilled athletes are compared to novice athletes in certain sport domains. In the majority of cases, experts have more experience with the sport and have learned to focus on the important visual cues which allow them to be successful in their skills. Cue usage is when the performers use specific sources of information to guide their action (Williams et al., 2004). Although cue usage can often be predicted from point-of-gaze data, in certain situations performers fixate gaze centrally and extract information from a variety of cue areas using peripheral vision (Williams et al., 2004).

Castaneda and Gray (2007) compared two methods of attentional focus for baseball batters: skill vs. environment (attending hand movement vs. attending bat movement) and internal vs. external (attending ball leaving the bat vs. attending an irrelevant environmental stimulus). Their research suggested that highly skilled baseball batters should direct their attention to the ball leaving the bat. This prevents their focus of attention from hindering their swing process and will allow the link between action and its observable effects to be improved (Castaneda & Gray, 2007). They suggested this was likely due to the fact that the player's motor movements have been ingrained in the skilled player's minds from the large amounts of practice over the years and are best performed when there are no interruptions. Also the players can link the action of their swing with the results of their swing. For novices, the authors felt directing their attention toward any part of their swing, either their hands or the bat, will lead them to the most success in the future (Castaneda & Gray, 2007). This is because they are just learning the skill and motor movements and still need to make some adjustments to improve their swing (Castaneda & Gray, 2007). These results could be applied to skilled vs. less skilled athletes of all sports to indicate to them what to focus on while practicing to improve their technique.

Singer, Cauraugh, Chen, Steinberg, & Frehlich (1996) designed simulated tennis conditions to investigate foot reaction time (RT) and body movement time (MT) of highly-skilled tennis players compared to beginners and also performed an analysis on visual search profiles in addition to anticipation speed and accuracy in decision-making. RT measures the time from the presentation of a stimulus to an initiation of a response while MT is the duration of the time to complete the act (Singer et al., 1996). The visual scanning profiles demonstrated that highly skilled and lower ability tennis players focused on a majority of the same cues in an effort to anticipate their opponent's shot. The authors found this surprising since there were 9 location areas. One major difference was observed; novices focused more on distal cues (e.g. opponent's head) to anticipate location of the ball as compared to the expert performer who fixated on more proximal cues (e.g. trunk, arms, hips). Experts also displayed a greater ability to predict ball direction of serves and ground strokes, and performing with less variable error than the novices. Fixating on certain cues and predicting ball direction were found to be more relevant than foot RT and body MT to separate the highly skilled group from the beginners in tennis. The results suggest that information extraction and anticipation are conceivably more crucial to being a skilled player than bodily reactions and movements (Singer et al., 1996). Overall these findings imply that novices may improve in anticipatory capabilities from instruction that directs their attention to more meaningful cues (Singer et al., 1996).

Ripoll, Kerlirzin, Stein, & Reine (1995) used a video recorded image of a boxer to develop a realistic scene for the subjects to watch and imagine fighting the player on the screen. The subjects were all boxers (French boxing). Six experts, six intermediates, and six novices made up the three groups of subjects. The video showed different situations to which subjects had to respond using a joystick. No significant differences were found between the groups in response to the attacks or openings during the simple situations. During the complex situations, results showed that experts were significantly more efficient in responding to attacks than intermediates or novices. Also no significant differences were found in relation to reaction time between the groups. It was found that experts had a significantly smaller number of fixations (M = 43.3 ± 17.12) than the intermediates (M = 105.8 ± 33.59), and novices (M = 122.67 ± 42.41). Although the experts had fewer fixations, they were found to be of longer duration than what the intermediates or novices used. They found that experts developed more economical visual search activity than less skilled subjects. Experts utilized what they called inter-event visual patterns involving a circular relation between selected cues while novices developed a more linear pattern. This circular and inter-event method resulted in a chunking process where objects that were in close proximity, combine into a pattern (Ripoll et al., 1995). Chunking processing, which has been recognized as a cognitive skill is said to be an essential aspect of skill acquisition (Ripoll et al., 1995).

Recent eye-gaze literature suggests that the expert athletes have fewer fixation locations, but these fixations are for a longer duration in comparison to less skilled athletes in those sports. Skilled athletes have the ability to extract relevant information from the key areas prior to the start of the action while at the same time maintaining a high level of concentration to prevent distraction from irrelevant task information (Williams et al., 2004).

Despite the research findings which suggest differences based on skill related to search behaviour, some conflicting findings have been reported (Williams et al., 2004). It can likely be explained by two frequently reported limitations: the ability to redirect attention within the visual field without making distinct eye movements to change the point of fixation, and the distinction between “looking” and “seeing” (Williams et al., 2004). Eye movements and the position of the eye only provide information about the orientation of the fovea, whereas in sport many situations require the integration of information from the fovea, parafovea, and visual periphery (Williams & Davids, 1998).

Research on ice hockey shooting is very limited in terms of the number of studies that have been performed up to this point. There are some studies which have recorded the kinematics of the shooters during ice hockey shooting, but gaze characteristics throughout this skill have yet to be evaluated. The literature has shown that gaze characteristics in sports which require precise aiming can be significant indicators of the level of accuracy of the athletes. Determining the gaze characteristics used during ice hockey shooting and combining this information with the kinematic data in the hockey literature may help to establish what an accurate shooter in ice hockey is doing prior to, and during, the execution of their shot that an inaccurate shooter is not. Once this information is discovered, it will make it possible to develop guidelines for ice hockey players to improve their shot accuracy.

Chapter 3: Methods

3.1 Subjects

For this particular study, 12 subjects participated in the following protocol. Men aged 18 to 30 varying in skill from high to low calibre were asked to participate in this project. Subjects were all healthy and selected from the university population. Subjects were recruited from both the McGill varsity team and the university recreational hockey population. Skill level was initially stratified based on current level of play during testing but shot accuracy scores were the determining factor of an accurate shooter (AS) or inaccurate shooter (IS) for group assignment post-hoc. Descriptive data for the amount of years played, ice hockey position, and highest level of competition for each subject were collected but not used to form accuracy groups. This was due to the fact that this data described the subject’s skill level rather than their shooting accuracy. It was discovered through pilot testing that skill level was not necessarily a determinant of accuracy which is why accuracy groups were formed post-hoc. Both left and right handed shooters were recruited. All subjects participating in the study had no significant visual impairments and subjects who normally wore corrective contact lenses were allowed to participate. Prior to testing, an ethics certificate was obtained and subjects read and signed a consent form in accordance with the Tri-Council Policy

Statement on Ethical Conduct for Research Involving Humans. Ethical approval for this study was obtained from the McGill University's ethics committee (REB #120-0910).

3.2 Task protocol

Two skills were combined for the task: the reception of a pass, and the wrist shot on the net. There were also two possible pass reception locations, forehand and backhand, that were randomly chosen by the passer. The subject was not informed where the pass was going to be directed during the trial. The purpose of delivering passes to the forehand or backhand without the player's prior knowledge was to force the subject to attend to the puck's location at all times. This made the scenario more game-like and helped to prevent the player from focusing on the targets when he was receiving a pass. It also helped to ensure that the maximum amount of shot preparation occurred after he had received the pass.

The skill of pass reception began when the stick of the player passing started in a motion toward the subject and ended when the puck reached the subject's stick. When the puck reached the subject's stick during a forehand reception he would normally manoeuvre the puck into a comfortable shooting position. If the pass was sent to the subject's backhand the players had to manoeuvre the puck from the backhand to their forehand in order to take a wrist shot. With a backhand reception, the pass reception skill again ended when the puck reached the subject's stick, but following the pass reception the subject was required to manoeuvre the puck from their backhand to their forehand and into their shooting position.

Time constraints

Often in open sports where athletes are competing directly with their opponents, they have to alter their strategies and movements based on what their opponent does. In hockey, the amount of time to make a decision and act on it is generally short. This is why two different time constraints were set up in this study. One time constraint defined as ‘time pressure’ required the subject to shoot the puck at a rapid pace after pass reception to make the task more game-like. In the second condition all constraints were removed as the subjects were allowed to take as much time as they felt necessary to take the shot after pass reception. This condition was defined as ‘no time pressure’. The skill of shooting was defined as and began immediately following the pass reception and continued until the puck reached the net from the wrist shot. The players were placed 4 m from the net for the task and had 2 possible targets on the net including top contralateral (TC) and top ipsilateral (TI). Each target was a square shape, and a size of 30 cm x 30 cm (Figure 3, below). Prior to each trial, subjects were instructed verbally to aim for a specific target which was randomly chosen by the passer. Subjects shot at each target 30 times for a total of 60 shots. Thirty passes were directed to the subject’s backhand, and 30 passes were directed to the shooter’s forehand, all shots with time pressure. Thirty additional shots were taken with no time pressure and the passes were directed to the subject's forehand for every trial during this task. The rationale for directing passes to only the forehand during this task was that it was expected that including backhand passes would simply reproduce the similar results to the forehand task. Backhand passes were included in the time pressure task because they added difficulty to the task under time constraints. For this task, where the subjects had unlimited time to prepare to shoot, adding backhand passes did not seem relevant.

3.3 Gaze variables

Task phases

The entire task was divided into 6 phases: pass release, pass follow, shot preparation, head transition, eyes on target, and shot release. *Pass release* began at the initiation of the pass motion towards the shooter and ended when the puck was no longer touching the passer's blade. *Pass follow* occurred immediately after pass release and continued until the point where the puck reached the stick blade of the shooter. *Puck preparation* time began at the point when the puck initially touched the stick blade of the shooter and continued as the shooter maneuvered the puck to a favourable position for shooting. *Head transition* was the time frame prior to shot release where the shooter moved his head from the puck/blade (which is on the ice) to the target. *Eyes on target* began when the gaze reached the target and ended when the puck was released from the stick during the shot. *Shot release* was the point where the puck was no longer in contact with the blade of the subject's stick after the wrist shot. These phases were defined to separate the different steps that each subject performed from the beginning of pass reception to the conclusion of the wrist shot. *Task time* (TT) was the duration of time the subject took to complete the task which began immediately after pass reception and ended when the puck reached the net. Figure 3.1 illustrates the first five phases of the task (*shot release* phase not included). Figure 3.2 separates the different phases of the task to give a better understanding of what is occurring at each one.

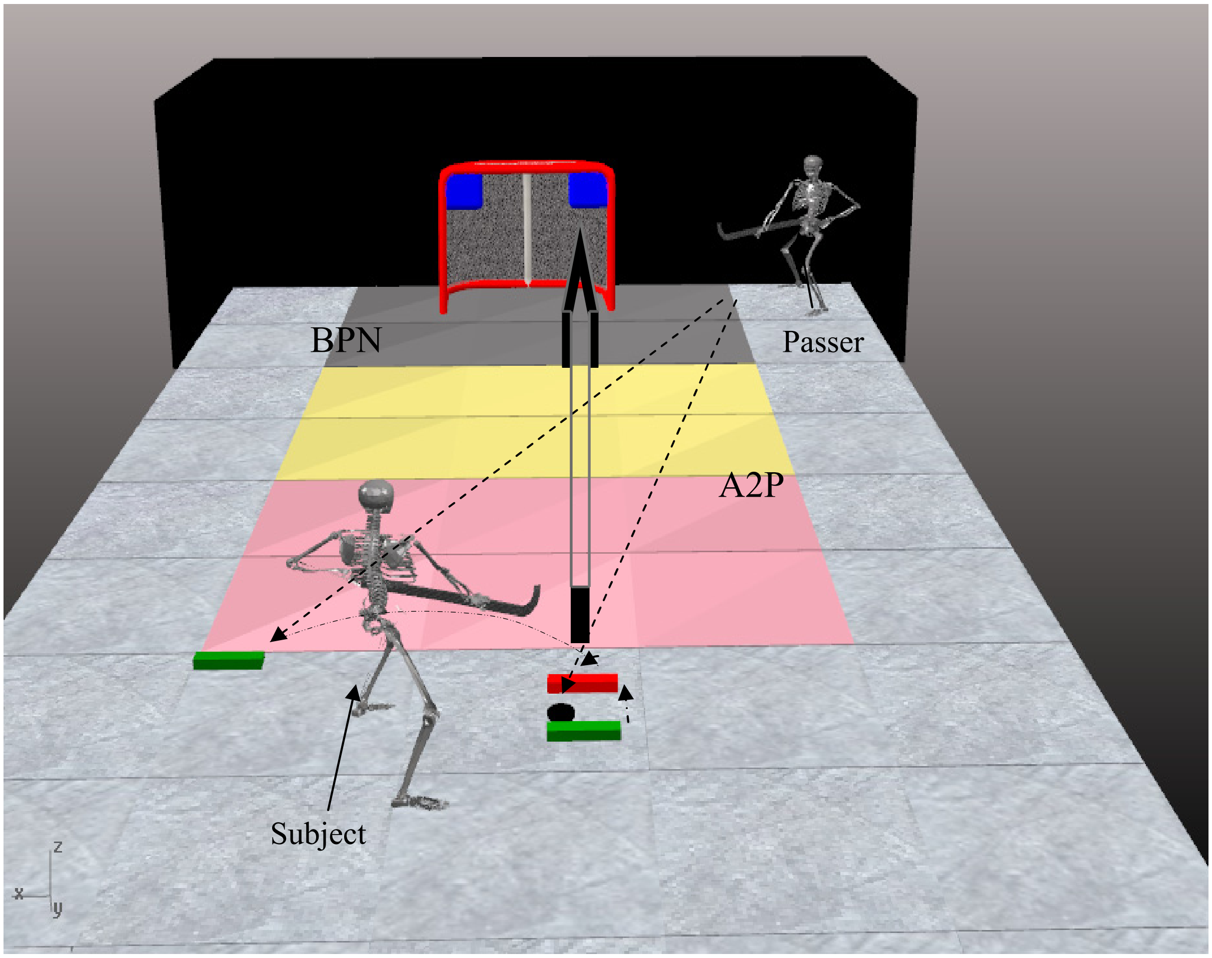

Figure 3.1: Illustration of a right-handed shooter in the testing protocol. Protocol began with pass toward the subject's forehand or backhand (both green). Once the pass was received the subject would begin preparation by moving the puck to an appropriate shooting position (red). The head would then transition from facing down at the puck to a position allowing gaze at the target. The shaded areas indicate different gaze locations (A2P, BPN, and IF) identified during the head transition phase. The final step was executing a wrist shot toward the target (large arrow)

Gaze locations

Pilot testing revealed ten different gaze locations/eye movements occurring over the course of the task for multiple subjects. These gaze locations were defined and included in the current study. During the *pass release* phase, the stick blade of the passer was the gaze location and the amount of time the gaze was focused on this area was computed. If the gaze was not within 50 pixels of the stick blade on the video then it was not considered to be on the stick blade. When the pass release phase was complete, the *pass follow* phase began. For this phase, the puck was the target location. Any gaze directed away from the puck was deemed not on the puck and was not included in the *pass follow* variable. The subject's used a gaze method known as "pursuit tracking", which meant that they focused on the puck and followed it for the entire duration of the pass. When the puck preparation phase began, the subjects started this phase with their gaze directed down at the puck. When the gaze was directed on the puck, this was coded as *on puck* (OP). At this point the *head transition* phase often overlapped with the *puck preparation* phase as the gaze was still focused on the puck but the head also started transitioning toward the net. During the head transition several different gaze strategies were observed which is why there were many variables coded during this phase. *Scan to net* (SN) was coded when the eyes of the subject would saccade towards the net. This was identifiable because the cross-hairs moved rapidly from one location to another in the direction of the net. *Stable gaze* (SG) was also a type of eye movement but was different than a SN as the movement did not occur as rapidly and was recognizable because the cross-hairs did not get disorganized as they did during SN. There were also 3 possible gaze locations during the head transition phase. *Anterior to puck* (AP) was a location one foot in front of the subject's stick to a stick length in front of them. *In front* (IF) was coded when the gaze was focussed directly in front of the net (on the ice) or just to the side of the net. *Between puck and net* (BPN) was any location on the ice between AP and IF (AP, BPN, and IF are depicted in Figure 3.1). Once the gaze reached the net, the *eyes on target phase* began. The gaze was either directed *on net* (EON) *or on target* (EOT) and was only coded if it occurred prior to the shot release. Gaze variables SN, SG, AP, BPN, and IF were combined to create a variable *puck to net* (P2N) which was used to describe the length of time it took each subject to transfer their gaze from on the puck to on the net or target. The final gaze variable calculated was the *total time on net/target* (TNT) which was simply a sum of EON and EOT.

Figure 3.2: Pictures taken of the different task phases for a subject during a forehand pass protocol. Red arrows indicate gaze locations during each phase. Puck begins at pass location in *pass release* phase (a). Puck was then passed to either the forehand or backhand of the subject in the *pass follow* phase (b). *Puck preparation* phase involved the subject gazing down as they move the puck into a comfortable shooting position (c). In the *head transition* phase the head moved from a position allowing gaze on the puck to a position favouring gaze at the net (d) (during this phase, the eyes would either scan towards the net or they would stop to focus on some location on the ice or a combination of both). The subject's gaze would now be focused on the net or target (e) just prior to the release of the wrist shot towards the target (f).

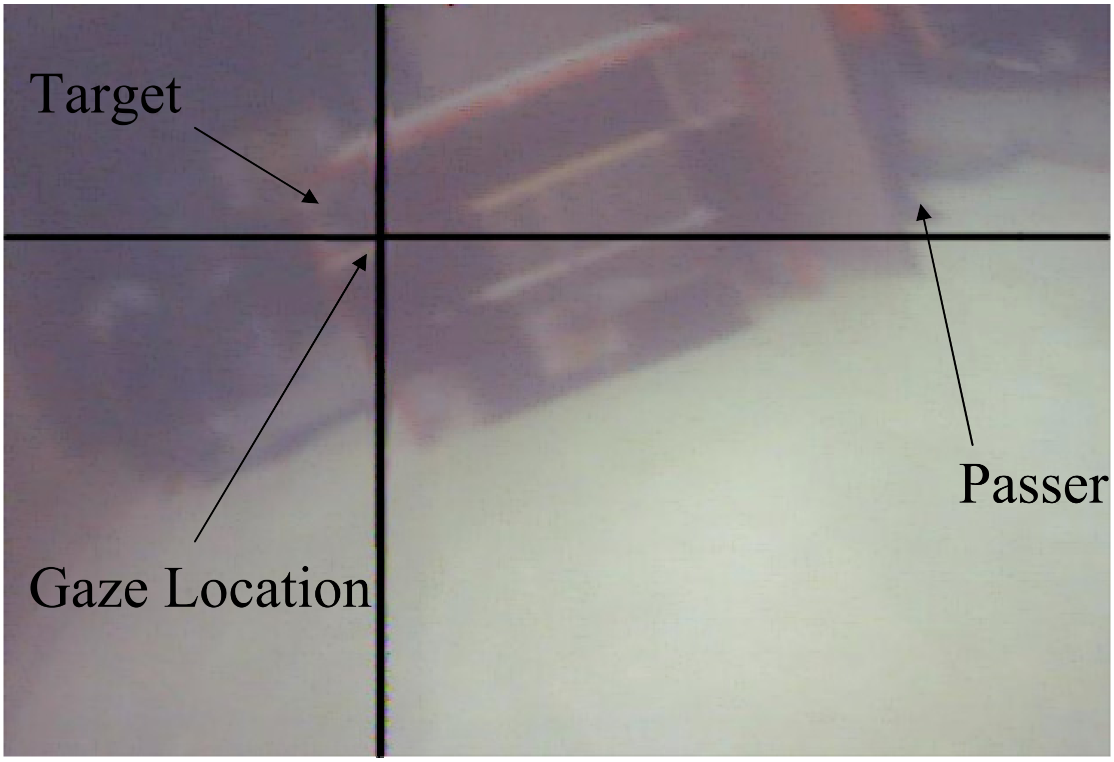

Figure 3.3: Photo displays a frame from the view of the scene camera of the Eye Tracking System. The subject (right-handed) was gazing at the top-contralateral target during the *eyes on target* phase which would have been coded as EOT for this particular frame.

3.4 Capture environment

Testing was performed on an artificial ice surface with the Model 501 Head Mounted Eye Tracker (Applied Science Laboratories, Bedford, MA). The Mobile Eye is a head-mounted, monocular eye-tracking system that uses corneal reflection to measure eye-line-of-gaze for the field of view for the subject with accuracy of 1 degree and with a precision of 0.5 degrees (Applied Science Laboratories, Bedford, MA). The Model 501 works by illuminating a beam onto the eye from an infrared source and the optical system focuses an image of the eye onto a video (eye camera). A second camera (scene camera) was aimed in a direction to represent the subject's field of view. The illuminator, optics, and both cameras are mounted on the helmet.

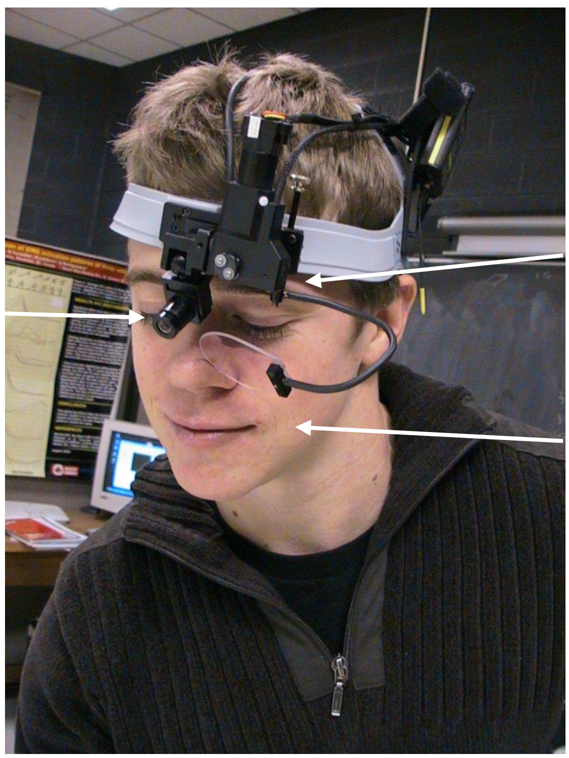

Figure 3.4: Model 501 Head Mounted Eye Tracker on a subject as worn during the testing protocol. Labelled are the scene camera, eye camera, and monocular lens.

A lens which is also part of the helmet was positioned near the cheek, and just under the eye of the subject. When positioned correctly, it reflects an image of the corneal reflection and a bright pupil on the pupil monitor. As the eye moves, the corneal reflection changes and the Model 501 calculates the amount of movement and adjusts the eye-line-of-gaze displayed on the scene camera. The eye-line-of-gaze is represented by cross-hairs shown on the scene camera video. This technology can be used on ice but the head mounted helmet worn by the players which is part of the eye tracker system is connected by a 2m long wire, so movement was restricted to that distance. Figure 3.4 (above) shows a subject wearing the Model 501 Eye Tracker.

The scene camera can be adjusted to be aimed at different areas surrounding the person. The objective was to have the camera aligned so that it would record a view of the environment in front of the subject while they were looking straight ahead (either at a player's stick or the net). There was also be an additional camera used (CASIO EX-FH20, CASIO Computer Co., Tokyo, Japan) which was not part of the Model 501 which was focused on the subject to capture their body movements during the shot. The purpose of this camera was to determine when the puck was released from the shooter's stick during the wrist shot. The stick and puck of the shooter were not in the view of the Eye Tracker camera when the puck was released which is why the additional camera was necessary. The Model 501 camera recorded at 50 Hz while the EX-FH20 records at 30 Hz. Both frequencies were matched in order to sync the two cameras.

Data coding

Data was coded using the recorded videos from the scene camera of the Eye Tracking System. An example of a frame from one of those videos is in figure 3.3 (above). MATLAB® codes were constructed prior to the testing. The codes converted the full videos of each trial into a number of frames. The amount of frames was dependent on the length of the video produced by the scene camera which was recording 50 frames per second. Each frame was tagged manually by a researcher in MatLab® to indicate what phase the subject was in as well as whether the subject was looking at the puck or the net or some other area. The only part of the task which could not be coded in MatLab® was when the gaze had reached the net. This was a due to too much head movement through the process of the wrist shot which resulted in the cross-hairs indicating the gaze moving sporadically. This sporadic movement of the cross-hairs gave an inaccurate coordinate of the gaze location which is why the gaze on net had to be calculated by hand. The CASIO camera, which recorded the whole body of the subject during the task, was used to acquire the time when the puck had been released from the stick during the shot. The puck release indicated the end of gaze variables EOT or EON.

3.5 Subject preparation

The subjects began by placing the eye tracker head piece on their head so that it was comfortable and stable. It then was adjusted so that the head band was approximately an inch above the eye brow and the lens was located in front of the left eye. For the best results the headband was adjusted so that it was tight enough to reduce the likelihood of the helmet moving during the actual testing, while still allowing the subject to be comfortable. The scene camera could then be adjusted, depending on the subject's height, to provide a scene where the puck would be in view during the pass reception and the net in view while taking the shot. Next, the lens which is also connected to the head piece was adjusted to capture a clear picture of the pupil and corneal reflection which was vital to being able to identify where they are looking. Once everything had been adjusted, the subject was required to look at a calibration matrix in order to calibrate the system. The calibration was performed with the 9 calibration points on the hockey net that the subject would be shooting at. The system was calibrated with the subject in a chair to reduce the movement of the head during this procedure. These points were manually set in the Model 501 system by the user and the system recorded the 2-D coordinates of the points. During calibration the subject looked at each of these 9 points to allow the system to initialize the cornea location for each of these points. The 9 calibration points are illustrated in Figure 3.5 (below), which also includes the distance between each point.

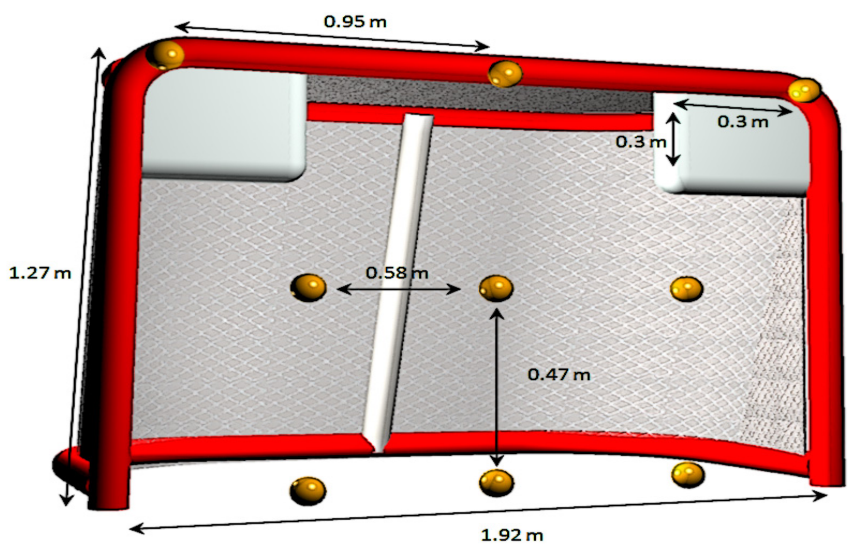

Figure 3.5: Virtual diagram of targets and 9 calibration points (yellow circles) that were used for the present study, along with dimensions of each.

The Model 501 system was able to precisely calculate where the subject was looking in their field of view based on the corneal reflection. Accordingly, when the subject moved their eyes during testing, the eye tracking system recorded where the subject was looking by displaying cross-hairs on the scene camera. One limitation of the eye tracker occurred when the subjects would keep their head straight and glance straight down. In these instances the scene camera could not capture where they were looking making the data unusable.

3.6 Task description

Once the Model 501 had been calibrated, the subjects were asked to gaze at each of the targets, as well as at a puck that was placed in the passer's position and at a puck placed in front of the shooter to ensure that the system had been calibrated correctly. If it had been, the crosshairs on the television that was connected to the Model 501 would display the cross-hairs on the area where the players were instructed to look. The subjects were then informed that the passer would be directing the puck to either their forehand or backhand but they would not be aware of which side it would be going (for the time pressure task only). The subjects were aware which target they had to aim for as they were notified prior to each trial. The subjects were given about five to ten minutes to practice and warm up. This time would help them to adjust to the eye tracker that was on their head, and this time was also used to help guide them towards an appropriate speed to perform the task. If the subjects did not perform the task in an appropriate amount of time, either too fast or too slow, they would be asked to adjust accordingly. The task was created to resemble a hockey situation as close as possible. When the subjects took a lot of time to shoot, it was less game-like and the results would be less meaningful. If the subjects shot the puck too fast and did not allow themselves to fixate on the target, this made the task much more difficult. Any trials during the time pressure condition that were too fast or slow were not considered valid and would not be included in the data analysis.

3.7 Research design

The design of this study was a two-way MANOVA design experiment. The independent variables examined each had two levels as seen in Table 3.1 below.

Table 3.1 Independent variables with respective levels

Independent Variable	Levels
Calibre of player	Accurate Shooter (AS)
	Inaccurate Shooter (IS)
Target	Top Contralateral(TC)
	Top Ipsilateral(TI)
Pass Reception	Forehand
	Backhand
Time Constraints	Time Pressure (TP)
	No Time Pressure (NP)

Several dependent variables were examined as described in Table 3.2.

Table 3.2 Dependent variables measured during experiment

Type	Variable description	Per subject	Per group	Per target	Per pass
Subject Descriptive	age	value	mean ± SD		
Gaze Characteristics	On puck (pass release)	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	Pass Follow	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	On puck (shot prep.)	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	Scan to net	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	Stable Gaze	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	Ant2Puck	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	Between Puck+Net	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	In Front	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	Gaze on Net	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	Gaze On Target	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	Task Time	mean ± SD	mean ± SD	mean ± SD	mean ± SD
Accuracy Scores	missed target	mean ± SD	mean ± SD	mean ± SD	mean ± SD
	hit target	mean ± SD	mean ± SD	mean ± SD	mean ± SD

Chapter 4: Results

4.1 Accuracy scores

Mean accuracy scores for each of the 12 subjects were calculated as the mean of each condition. The overall mean score was used to assign the players to the accuracy group AS or IS. To be included into the AS group the subject needed to have an overall mean accuracy score greater than 50% (greater than 45 out of 90 shots). Subjects not scoring above 50% made up the IS group. Of the 12 subjects tested, 5 attained a score above 50% accuracy allocating them to the AS group, with the remaining 7 subjects assigned to the IS group. Mean accuracy scores for the AS group from 55.6% to 66.7% and for the IS group ranged from 11.1% to 35.6% (Figure 4.1). Results of the one-way ANOVA comparing accuracy scores across groups showed a significant difference ($p \leq 0.001$). Full result details of all variables can be viewed in Appendix A.

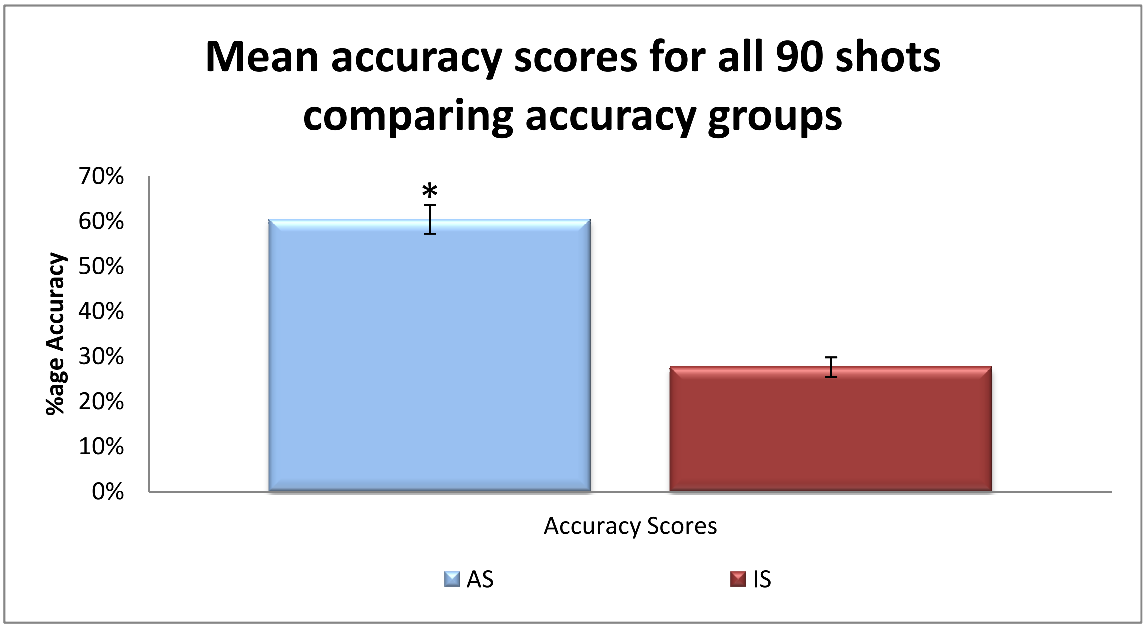

Figure 4.1: Comparison of the accuracy groups AS and IS and their accuracy scores after 90 wrist shots. Data are means ± SE for accuracy scores. * $p \leq 0.001$.

4.2 MANOVA of test conditions

Statistics were performed using SPSS (IBM® SPSS® Statistics, Version 17.0). Once players were divided into AS and IS groups, 4 two-way MANOVAs were conducted so as to interpret the effects of different conditions, including side of pass reception (forehand and backhand) and time constraints conditions (time pressure and no time pressure) on the gaze characteristics.

4.2.1 Forehand reception / wrist shot with time pressure

Significant differences were found for puck to net (P2N) and time on net and target (TNT) during the forehand pass reception task under time pressure. Accuracy group and condition were the independent variables. P2N was the mean time required for gaze transition from the puck to the net or target. The duration of P2N was significantly longer for IS (0.238 s ± 0.019) than for the AS group (0.157 s ± 0.023). The variable TNT indicated that the AS group gazed at the net and target significantly longer than the IS group with durations of 0.191 s ± 0.020 and 0.136 s ±0.017, respectively (Figure 4.2).

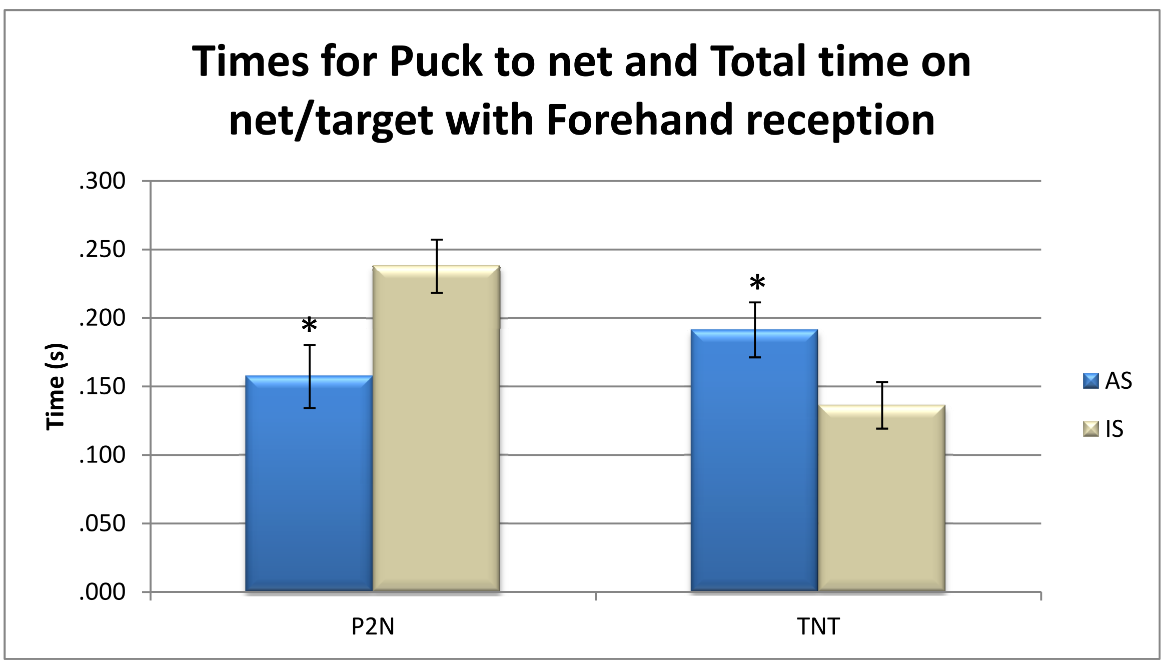

Figure 4.2: Values obtained during the forehand task with time pressure for each accuracy group. Based on accuracy group, significant differences were found for

gaze variables P2N ($p < 0.014$) and TNT ($p < 0.049$). Data are means ± SE for time. * $p < 0.05$.

A time-graph (figure 4.3) was produced to help explain the order in which the gaze variables occurred over the course of the task. It also helps to show the duration of each variable in comparison to others, as well as compared to the total task time. Although this graph shows the duration of the task, the variable *task time* (TT) did not begin until the puck had reached the subject's stick. When the variable *on puck* (OP) begins, this marks the point when the puck has reached the subject's stick blade. Gaze locations *anterior to puck* (A2P), *between puck and net* (BPN), *in front* (IF), and *stable gaze* (SG) were not included in the diagram because of their extremely small durations. Their values, as well as the *scan to net* (SN) were included in *puck to net* (P2N) as this was how it was calculated. Only a time-graph for the accurate shooting group (AS) was shown and this was due to the fact that the inaccurate shooting group (IS) time-graph appeared too similar to the AS group graph. Although there were significant differences between the groups gaze characteristics, these differences were under represented when comparing the two time-graphs. This was due to the small interval of time required for some of the gaze characteristics. The gaze characteristics that showed significant differences between groups, which also occurred over short durations did not appear to have differences when comparing the graphs visually.

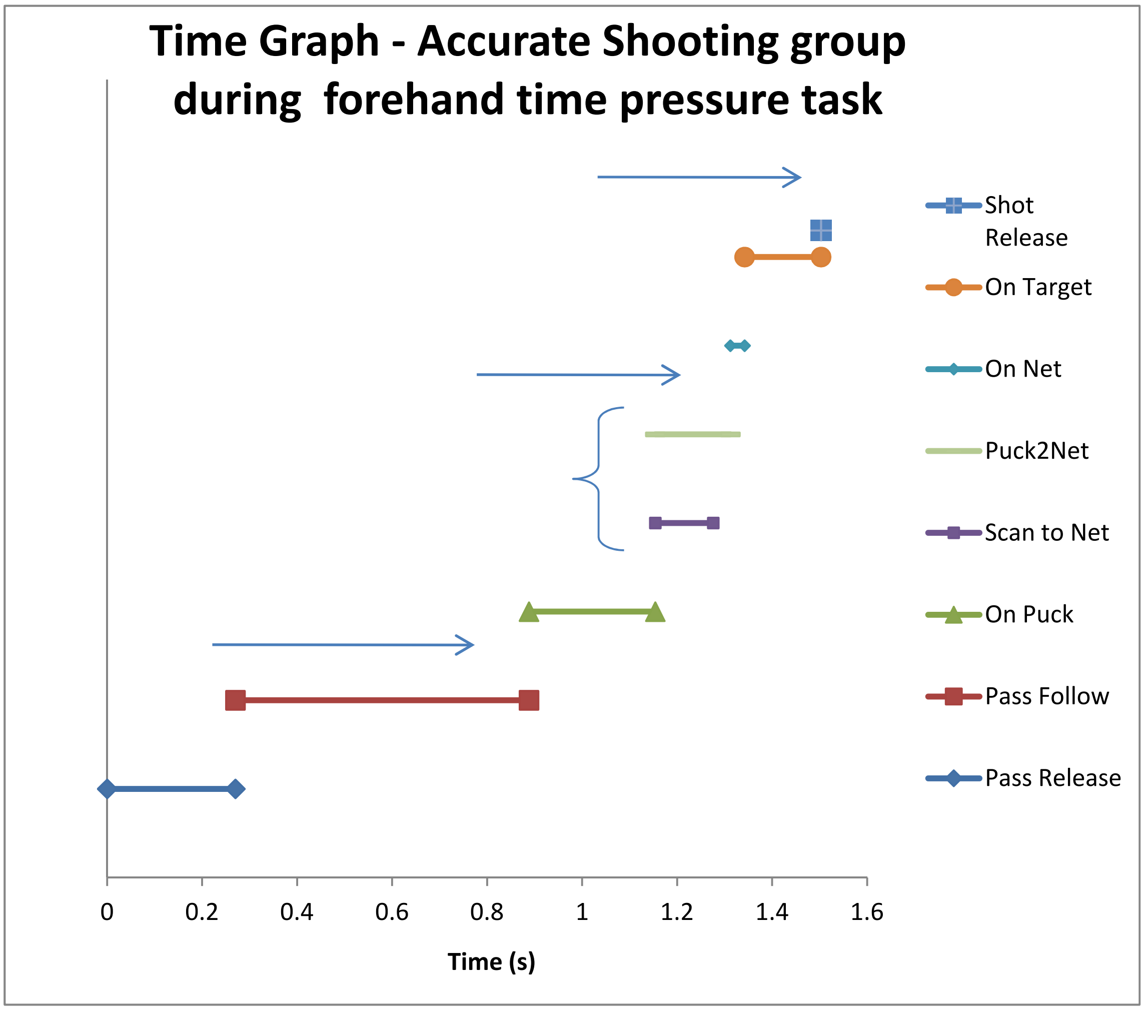

Figure 4.3: A time-graph of the mean times for the accuracy group AS during the forehand time pressure task. The different variables shown indicate the time frame in which different gaze characteristics occurred over the course of the task.

4.2.2 Backhand reception / wrist shot with time pressure

Significant differences between accuracy groups were noted in gaze variables *scan to net* (SN), *eyes on target* (EOT), and *time on net and target* (TNT) during the backhand time pressure task. The gaze variable SN, which was the duration of time that a subject's eyes saccaded in the direction of the net, was significantly longer for the IS group (0.136 s ± 0.008) than for the AS group (0.107 s ± 0.010). The AS group (0.218 s ± 0.023) had a duration which was significantly longer for the variable EOT than the IS group (0.130 s ± 0.020). The variable TNT also showed a significant difference between the AS group (0.256 s ± 0.022) and the IS group (0.156 s ± 0.019). Figure 4.4 (below) illustrates the differences between the two accuracy groups and the significant variables.

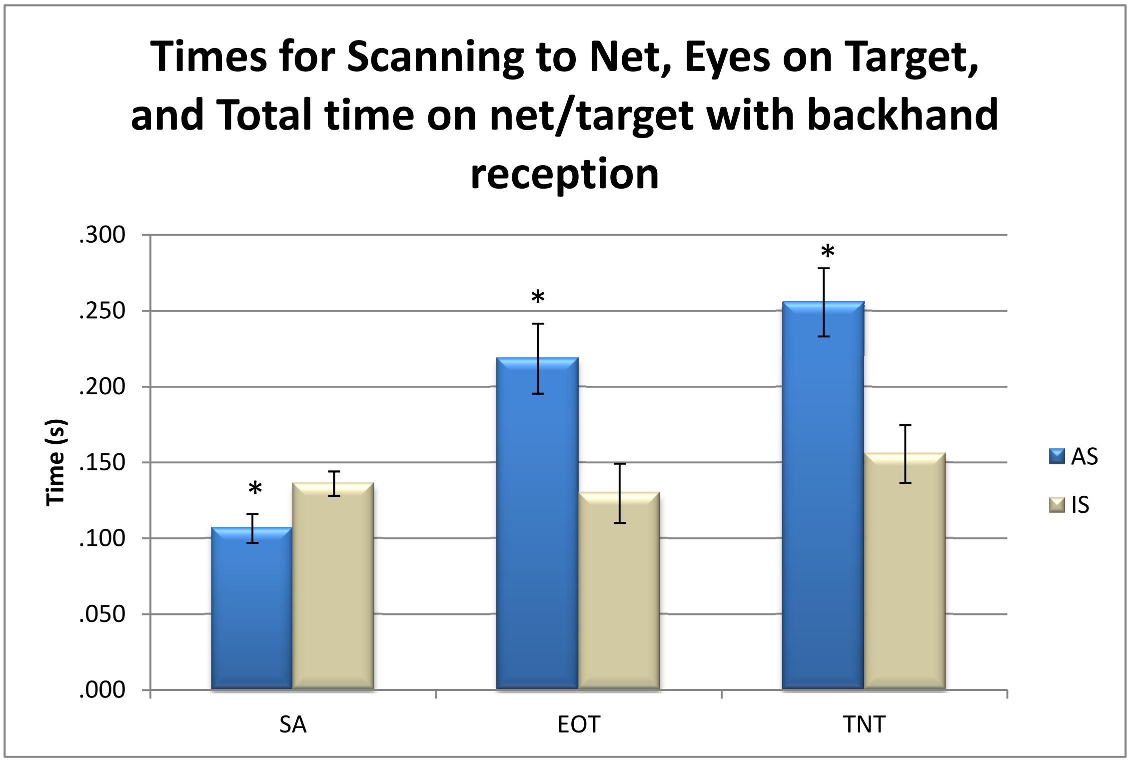

Figure 4.4: Values obtained for each accuracy group during the backhand reception task with time pressure. Based on accuracy group, significant differences for SN, EOT, and TNT were found which were p< 0.028, p< 0.008, and p< 0.003, respectively. Data are means ± SE for time. * p < 0.05.

4.2.3 Forehand reception / wrist shot with no time pressure

No significant results were found after a two-way MANOVA was performed on the no time pressure condition which had accuracy groups and conditions as the independent variable. Visual comparisons of the AS and IS groups can be seen in Figure 4.5 and Figure 4.6.

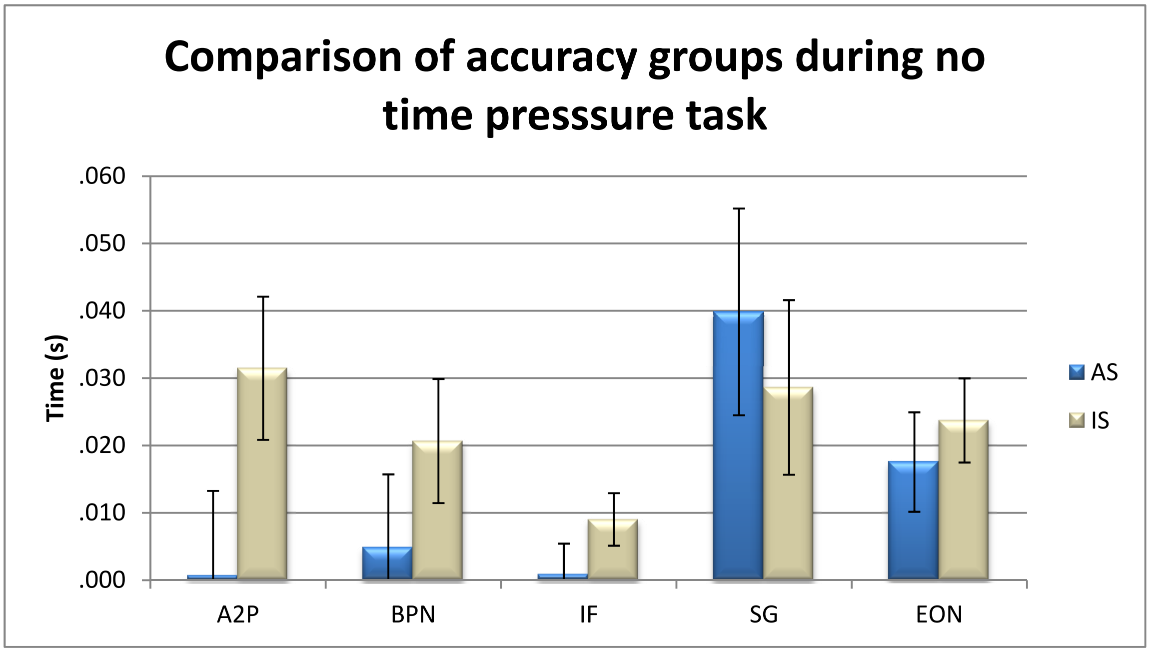

Figure 4.5: Depicted above are the mean values of several gaze characteristics during the no pressure tasks. Data are means ± SE for time. A two-way MANOVA was performed to compare accurate and inaccurate groups. No significant differences were found.

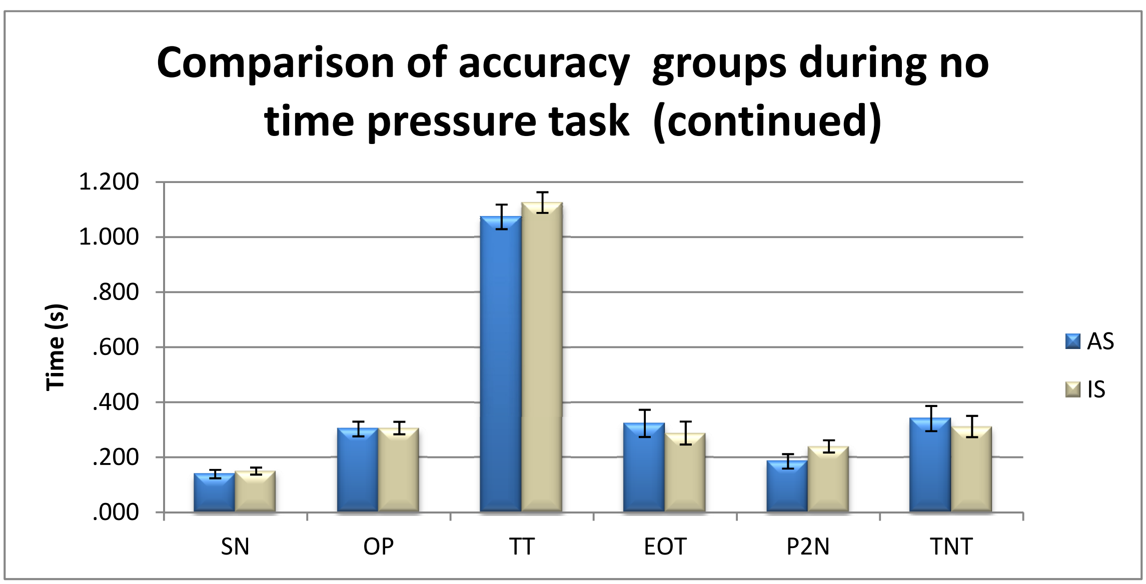

Figure 4.6: The illustration above shows the mean values of gaze characteristics during the no pressure tasks. Data are means ± SE for time. A two-way MANOVA was performed to compare accurate and inaccurate groups. No significant differences were found.

4.3 Comparison of tasks with time pressure and no time pressure

An ANOVA was performed on the results of the accuracy scores during the forehand reception / wrist shot with and without time pressure. The AS group improved their accuracy scores significantly from 57.3% ± 4.3 in the time pressure condition to 70.7% ± 4.3 in the no time pressure condition. The IS group did not show any significant improvements in their accuracy as their results were 28.1% ± 4.0 for the time pressure condition and 30.0% ± 4.0 in the no time pressure condition. Comparisons of the accuracy results are depicted in Figure 4.7 (below).

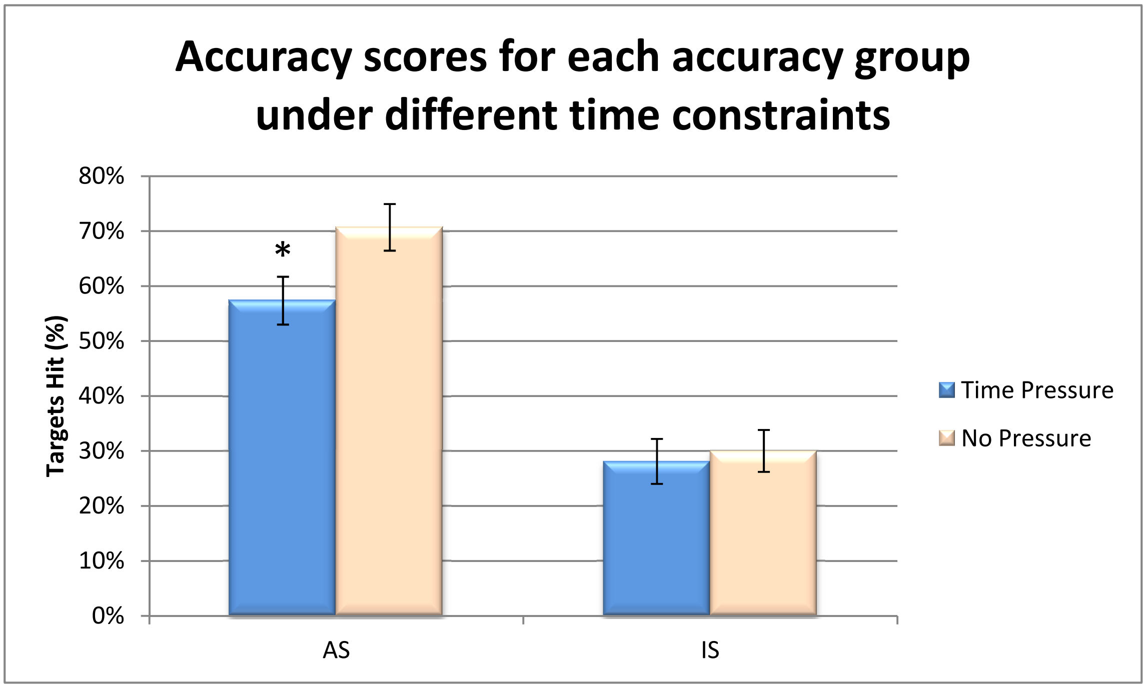

Figure 4.7: Accuracy scores for each accuracy group comparing their results under the two different time constraint tasks. The AS group showed significant differences across conditions ($p< 0.042$). Only results of the forehand task from the time pressure condition were used for any comparisons between time pressure and no time pressure conditions. * $p < 0.05$ within the group.

One-way MANOVAs were conducted using the data of each accuracy group to determine if the groups modified any of their gaze characteristics when the time constraints of the task were changed. Significant differences were revealed for both accuracy groups across conditions. Both the AS and IS groups significantly increased the duration of their *task time* (TT) as well as the gaze variables EOT and TNT during the no time pressure condition. The AS group had a significantly longer duration of TT for the no time pressure condition (1.073s ± .037) than the time pressure condition (0.882s ±.037). A significant increase in duration was also found for the gaze variable EOT as the AS group gazed on the target for 0.161s ± .027 in the time pressure condition and 0.323s ± .027 in the no time pressure condition. A significant difference was found for the gaze variable TNT as well, as it increased from 0.191s ± .024 for the time pressure condition to 0.340s ± .024 for the no time pressure condition. These results are displayed in figure 4.8 (below).

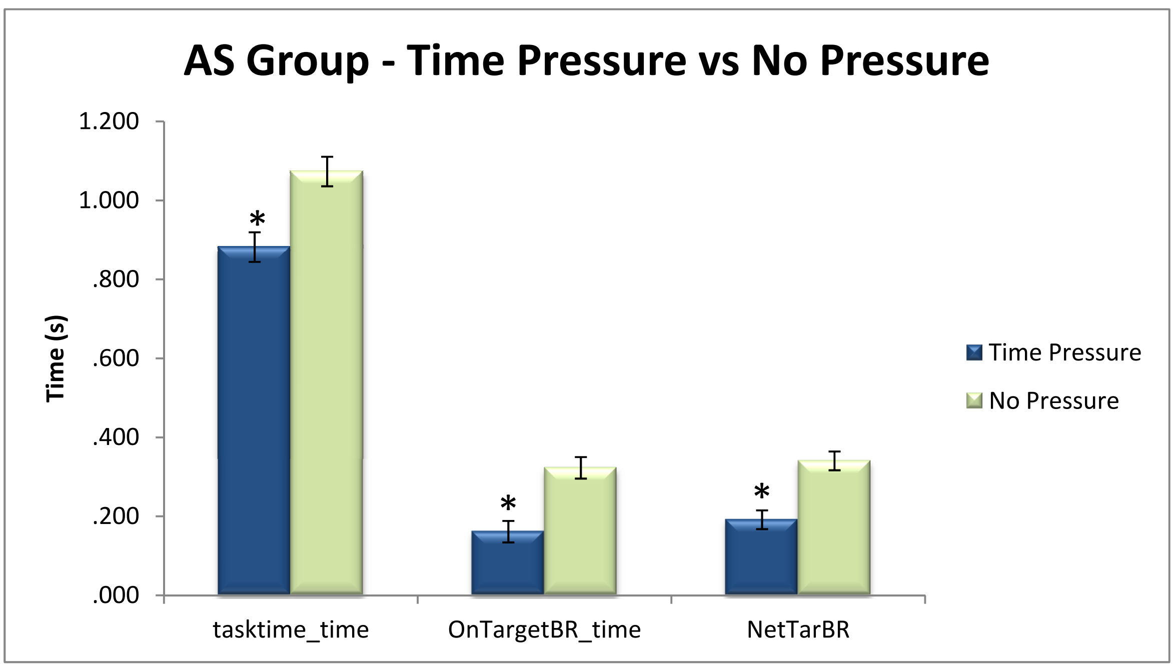

Figure 4.8: Displays variables that changed significantly as the time constraints of the task changed for the AS group. Only data from the forehand task of the time pressure condition was used for comparisons with the no time pressure

condition. Variables TT, EOT, and TNT showed significant differences of $p < 0.002$, $p < 0.001$, and $p \leq 0.0001$, respectively. * $p < 0.05$

The IS group significantly increased the duration of their task time (TT) from 0.859s ± .033 for the time pressure condition to 1.125s ± .033 for the no time pressure condition. In addition, their eye was on target (EOT) for a longer duration for the IS group in the no time pressure condition (0.288s ± .035) compared to the time pressure condition (0.121s ± .035). The IS group also increased the duration of gaze on net and target (TNT) from 0.136s ± .034 for the time pressure condition to 0.311 ± .034 for the no time pressure condition. Results are displayed in Figure 4.9 (below).

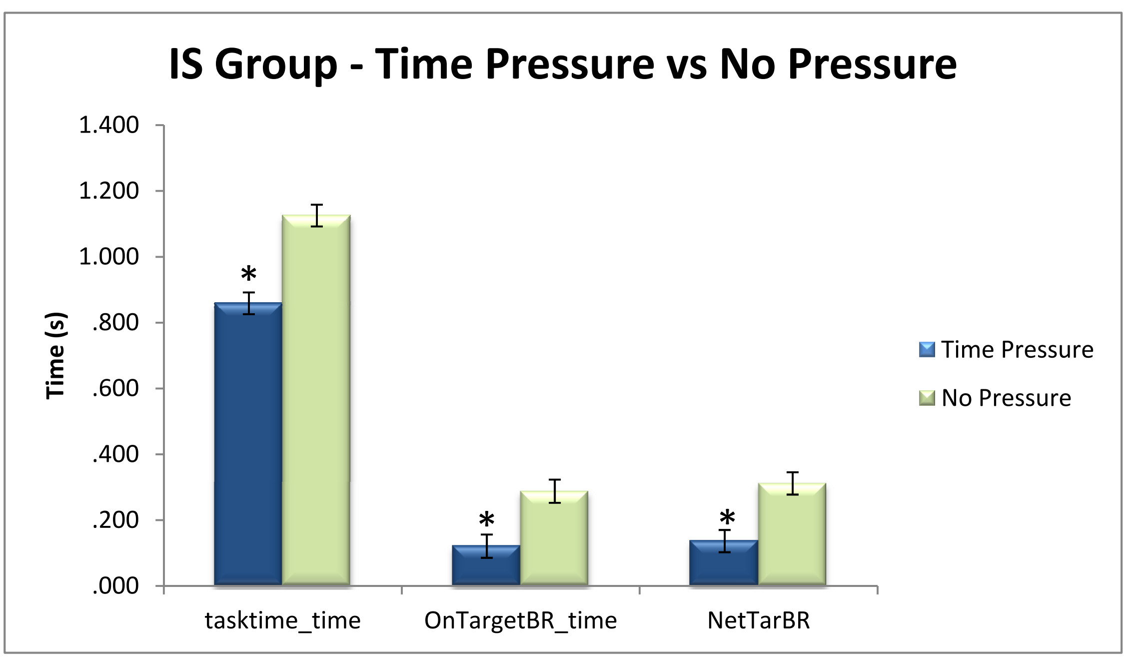

Figure 4.9: Displays variables that changed significantly as the time constraints of the task changed for the IS group. Only data from the forehand task of the time pressure condition was used for comparisons with the no time pressure condition. Variables TT, EOT, and TNT showed significant differences of $p \leq 0.0001$, $p < 0.003$, and $p < 0.001$, respectively. * $p < 0.05$

Chapter 5: Discussion

The purpose of this study was to identify gaze characteristics of hockey players during the sequence of two tasks: puck pass reception (forehand and backhand) followed by wrist shot of the puck at one of two defined upper net target locations. In addition, the same task sequences were tested under two time constraint conditions: with and without time pressure. Gaze characteristics were compared between accurate and inaccurate shooting groups. Based on a criteria of overall accuracy score, of the twelve subjects that were included in the study five subjects were placed in the AS group (Accurate Shooting) while the remaining seven were in the IS group (Inaccurate Shooting). As anticipated, significant gaze characteristic differences were noted between these groups during some of the test conditions.

For instance, during forehand reception / wrist shot with time pressure some significant gaze differences between the AS and IS groups were revealed. It was originally thought that the gaze on target (EOT) alone would be longer for the AS group yet no significant differences from IS were discovered. In effect, it was the combination of both gaze on net and gaze on target prior to shot release (EON + EOT = TNT) that distinguished AS for this task. The fact that the AS group was gazing at the target and/or net for a longer duration than the IS group is consistent with much of the gaze literature in sports; such that elite athletes often focus on the target of interest in their respective sports for longer durations than the non-elite athletes (Behan & Wilson, 2008; De Oliveira et al., 2006; Rodrigues et al., 2002; Vickers, 1996; Vickers & Williams, 2007). Although EON and EOT alone did not show significant differences between the two accuracy groups, combining each variable did reveal a significant difference. This suggests that directing gaze at the target and/or net for a longer duration allows for more accurate shooting in ice hockey.

EON indicated that the subject's central gaze (and inferred attention) was directed on the net. When the subjects were approaching the end of the *head transition* phase, their eyes would typically saccade in the direction of the net and continue to a point where they could focus on the target. However, in a more uncommon approach, some subjects would stop the *head transition* phase once their gaze had reached the centre of the net (coded as EON). Their focus would stay at this location for a brief moment, and eventually shift to the appropriate target (coded as EOT) where it would remain for the rest of the shot process.

This sequence of visual attention could be due to the fact that the subjects are accustomed to shooting on a goaltender, and may gaze at the goaltender (who is normally positioned in the centre of the net) first to identify open targets. Once a shooter recognizes an open target his gaze will transfer to this location. This interpretation is supported by Fehd & Seiffert (2008) who suggested that when tracking multiple objects (i.e. open targets around a goaltender) subject's tended to look at the centre of the array of objects. Williams et al. (2004) explained that although cue usage can help predict point-of-gaze data, in some situations the performers may fixate their gaze centrally and extract important cues using peripheral vision. These two points help to explain why some subjects initially gazed at the centre of the net. The offensive player in ice hockey must search for openings around the goalie that will allow the puck to reach the net.

It must also be considered that even when the line-of-gaze was directed at the centre of the net which was coded as EON, this did not imply that they could not view the target in their periphery. This is also true when their gaze is directed at the target. The subject is still able to view the net with their peripheral vision. While we can determine the central fixation point with the Eye Tracker we are not able to know where their attention is being directed or what cues the shooter's are using during the shot process.

The results also indicated that the IS group took significantly longer than the AS group to transfer their gaze from the puck during the *puck preparation* phase to the net or target to mark the beginning of the *eyes on target* phase. This portion of the skill was represented by the variable P2N. This was not originally anticipated, but this suggests that more skilled players transfer their gaze attention more quickly following puck reception and pre-shot positioning of the puck.

The backhand reception / wrist shot time pressure condition revealed some significant differences between accuracy groups as well. Variables EOT and TNT were substantially greater for the AS group. This finding is consistent with other gaze literature in sports wherein skilled athletes will focus on the target for a longer duration than less skilled during aiming tasks (Behan & Wilson, 2008; De Oliveira et al., 2006; Oudejans et al., 2002; Rodrigues et al., 2002; Vickers, 1996; Vickers & Williams, 2007). Vickers (1996) suggests that a fixation of long duration is necessary to effectively prepare for the numerous parameters of the shot, including distance to the target, the force and trajectory required to direct the ball (or puck in our case), the timing, and the coordination of the limbs. Vickers (2006) believed that fixating on the target for too short of duration was not optimal for the organization of the neural structures involved in complex movements. This idea could help to explain why the AS group in the current study gazed at the target for a longer duration than the IS group.

The total amount of time that the subject's eyes would shift towards the net (SN) during the *head transition* phase was significantly longer for the IS group. The inverse of this variable was representative of the speed at which the eyes moved towards the net during the preparation of the shot i.e. AS shifted their attention faster to the net. In a study by Philips & Edelman (2007) which measured the effects of learning on saccadic visual search tasks found that all of their subjects had significantly increased their search speed after weeks of performing the tasks. This improvement was highly correlated to an increased number of items scanned per fixation as well as increased amplitude of saccades. Philips & Edelman's findings complement the current study's results for AS shooters: as gaze attention reached the target faster, more time was allowed to focus on the target.

The idea the AS group was able to shift their eyes (saccade) toward the net in less time may help to explain why the variable P2N is significantly different in the forehand pass reception task. Although SN was not found to be significantly different between the accuracy groups for that task, there is an obvious difference in their values. Also the value of SN contributes the largest portion of gaze variable of P2N for both accuracy groups.

In addition to the above, gaze characteristics were dependent on time pressure. With no time pressure, no significant differences in gaze measures existed between the AS and IS groups for any of the variables measured. This suggests that when the two accuracy groups have unlimited time to shoot (time is not a factor), their gaze characteristics become more similar compared to when time is a factor. With no time pressure, the AS group was able to significantly improve their accuracy results, which is arguably due in part to further increased gaze time on the target in comparison to the time pressure task.

Similar increases in gaze net / target attention were shown by the IS group; however, no accuracy score improvements occurred. This lack of improved IS group accuracy can likely be attributed to other factors; for example, body movement coordination as measured using kinematics have been shown to be a strong predictors of shot success (Michaud-Paquette et al., 2008; Michaud-Paquette, Y., Magee, P., Pearsall, D.J., & Turcotte, R.A., 2011). Therefore even though the IS and AS groups displayed similar gaze behavior under no time constraints, the “poor” kinematic movements of the IS group may well have been the predominant factor in shot accuracy outcome. The importance of body kinematics in ice hockey shooting must be acknowledged as they represent a large element of what describes an accurate shooter. Regardless of the gaze characteristics that an ice hockey player employs, if their kinematics are extremely poor, their overall accuracy shooting will likely be the same. Considering this point, in the future, an ice hockey study where gaze characteristics as well as body kinematics are measured may help to determine the most significant differences between the IS and AS shooting groups in terms of what leads them to accurate shooting. Alternatively, IS and AS group's differences in how gaze information is interpreted may also explain the success differences.

A baseball study by Castaneda and Gray (2007) compared players of different skill levels to determine where the focus should be while swinging the bat. Their research suggested that highly skilled baseball batters should focus on the ball leaving the bat. They felt that the skilled player's motor movements had been ingrained in their mind due to the immense amount of practice. By gazing at the ball leaving the bat they would have the ability to link the action of their swing with the batting result. The research also suggested that less skilled batters should focus on either their hands or the bat in order to improve their motor movements by making adjustments accordingly. Although shooting in ice hockey and batting in baseball are different in many ways, both tasks require the athlete to use a tool (stick and bat) to propel the object in a desired trajectory.

The Castaneda and Gray (2007) study introduces an interesting idea for shooting in ice hockey. If subjects in the IS group focused more of their attention on the blade of the stick rather than on the target of the net throughout the process of the shot would this lead to better accuracy results? This could be a way for them to monitor the movements of their stick during successful (accurate) and unsuccessful (inaccurate) shots allowing them to make adjustments in the subsequent shots. This may help to improve their shooting kinematics, ultimately reducing the gap in their abilities with members of the AS group. As the less skilled shooters transition closer to becoming an accurate shooter, it would eventually become appropriate to utilize the same gaze attributes as members of the AS group in order to improve their accuracy results.

If this study were to be repeated, some sections of the methodology would require some adjusting. The assistant in the testing who was passing the puck to the subject attempted to be as consistent as possible in terms of the speed of the pass, as well as where he directed the pass. There was a target marked for where the pass was to be directed but the assistant did not have the ability to make a perfectly consistent pass every time which was expected. The assistant had the authority to decide if a trial was unusable based on the pass, but this was a decision based on a subjective opinion. A more formal procedure to measure the speed and location of the pass should have been in place to ensure that the passes were consistent for each subject on each trial. Another issue with the methodology was the timing of the shooting in the time pressure task. The subject was asked to shoot the puck in a short period of time after receiving the pass although no specific duration of time was given. The period of time that was appropriate was decided by the testers based on their subjective opinion. This made it difficult to ensure that each trial was performed consistently for each subject and also that each subject was performing the task under similar time pressures.

Conclusion

The rationale for performing this study was to determine whether any differences in gaze characteristics existed between accurate shooters and inaccurate shooters. The results revealed that accurate shooters gazed at the target and/or net prior to shot release for a longer duration of time than inaccurate shooters which was in agreement with our hypothesis based on previous literature for gaze in sport. It was also discovered that the inaccurate shooters spent a significantly longer amount of time to transfer their gaze from the puck (which was on the ice) to the net. This can partly be explained by the fact that the inaccurate shooters did not shift their eyes (saccade) as fast as the accurate shooters. The results also showed that the accurate and inaccurate groups had similar gaze characteristics in the no time pressure tasks, but only members of the accurate group were able to take advantage of the additional time to improve their accuracy. The lack of improvement in accuracy for the inaccurate group was likely due to poor kinematic movements during the shot process. It may be more advantageous for less-skilled (inaccurate) shooters to use different gaze characteristics than the more-skilled (accurate) shooters to help in the development of their kinematics which may lead to more accurate shooting in the future.

In future studies it may be more appropriate to have a goaltender in net to determine if or how this affects the gaze characteristics of the shooter compared to the current study. A future study where kinematics as well as gaze characteristics are measured may help verify what characteristics of accurate shooters are the most important in allowing them to be accurate. It might also be important in future studies to determine whether the shooters are putting forth maximal effort in their shot velocity. It reduces the difficulty of the task when a shooter uses less force than they are capable of, in order to become more accurate.

Differences in gaze characteristics between accurate and inaccurate shooters were discovered when they performed a task under time pressure. Determining if these differences exist, or if there are any more discrepancies when a goalie is present in the net may be the next step for future studies.

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Appendix A

Table A.1: Comparison of accuracy scores between accurate group and inaccurate group

		M	SE	n	F	*p*
Variable	Accuracy					
Mean Accuracy Scores	IS	.276	.022	42	76.739	.000
	AS	.604	.032	30		

Table A.2: Forehand pass reception with time pressure gaze variable times

		M	SE	n	F	*p*
Gaze Variable	Accuracy					
AP	IS	.038	.011	14	4.208	.054
	AS	.004	.013	10		
BPN	IS	.021	.008	14	1.566	.225
	AS	.006	.009	10		
IF	IS	.009	.004	14	1.411	.249
	AS	.003	.004	10		
SN	IS	.150	.010	14	3.509	.076
	AS	.122	.011	10		
OP	IS	.238	.024	14	.575	.457
	AS	.266	.028	10		
P2N	IS	.238	.019	14	7.186	.014
	AS	.157	.023	10		
SG	IS	.020	.010	14	.051	.823
	AS	.023	.011	10		
TT	IS	.859	.029	14	.260	.616
	AS	.882	.035	10		
EON	IS	.015	.006	14	2.950	.101
	AS	.030	.007	10		
EOT	IS	.121	.017	14	2.443	.134
	AS	.161	.020	10		
TNT	IS	.136	.017	14	4.410	.049
	AS	.191	.020	10		

Table A.3: Backhand pass reception with time pressure gaze variable times

Gaze Variable	Accuracy	M	SE	n	F	*p*
AP	IS	.068	.013	14	.224	.641
	AS	.059	.015	10		
BPN	IS	.071	.023	14	1.681	.210
	AS	.024	.028	10		
IF	IS	.031	.009	14	1.391	.252
	AS	.016	.010	10		
SN	IS	.136	.008	14	5.620	.028
	AS	.107	.010	10		
OP	IS	.512	.037	14	.183	.673
	AS	.487	.044	10		
P2N	IS	.315	.035	14	3.192	.089
	AS	.219	.041	10		
SG	IS	.008	.006	14	.295	.593
	AS	.013	.007	10		
TT	IS	1.230	.044	14	.043	.838
	AS	1.216	.052	10		
EON	IS	.026	.010	14	.548	.468
	AS	.037	.012	10		
EOT	IS	.130	.020	14	8.630	.008
	AS	.218	.023	10		
TNT	IS	.156	.019	14	11.526	.003
	AS	.256	.022	10		

Table A.4: All variables measured for no pressure task comparing accuracy groups						
		M	SE	n	F	*p*
Gaze Variable	Accuracy					
AP	IS	.031	.011	14	3.492	.076
	AS	.001	.013	10		
BPN	IS	.021	.009	14	1.233	.280
	AS	.005	.011	10		
IF	IS	.009	.004	14	1.844	.190
	AS	.001	.005	10		
SN	IS	.150	.013	14	.295	.593
	AS	.139	.015	10		
OP	IS	.306	.023	14	.010	.922
	AS	.303	.027	10		
P2N	IS	.239	.022	14	2.503	.129
	AS	.185	.026	10		
SG	IS	.029	.013	14	.312	.583
	AS	.040	.015	10		
TT	IS	1.125	.038	14	.794	.383
	AS	1.073	.045	10		
EON	IS	.024	.006	14	.407	.531
	AS	.018	.007	10		
EOT	IS	.288	.042	14	.295	.593
	AS	.323	.049	10		
TNT	IS	.311	.039	14	.232	.635
	AS	.340	.046	10		

Table A.5: Comparison of accuracy scores for accurate group in time pressure condition and no time pressure condition						
		M (%)	SE	n	F	*p*
Variable	Condition					
Mean Accuracy Scores	TP	57.3	4.4	10	4.813	.042
	NP	70.7	4.2	10		

Table A.6: Comparison of accuracy scores for inaccurate group in time pressure condition and no time pressure condition						
		M (%)	SE	n	F	*p*
Variable	Condition					
Mean Accuracy Scores	TP	28.1	4.1	14	.116	.736
	NP	30.0	3.8	14		

Table A.7: Comparison of gaze variables for accurate group in time pressure condition and no time pressure condition

Gaze Variable	Condition	M	SE	n	F	*p*
AP	TP	.004	.002	10	1.357	.259
	NP	.001	.002	10		
BPN	TP	.006	.005	10	.014	.907
	NP	.005	.005	10		
IF	TP	.003	.001	10	.937	.346
	NP	.001	.001	10		
SN	TP	.122	.013	10	.886	.359
	NP	.139	.013	10		
OP	TP	.266	.023	10	1.265	.275
	NP	.303	.023	10		
P2N	TP	.157	.010	10	3.862	.065
	NP	.185	.010	10		
SG	TP	.023	.017	10	.460	.506
	NP	.040	.017	10		
TT	TP	.882	.037	10	13.072	.002
	NP	1.073	.037	10		
EON	TP	.030	.007	10	1.881	.187
	NP	.018	.007	10		
EOT	TP	.161	.027	10	17.637	.001
	NP	.323	.027	10		
TNT	TP	.191	.024	10	19.593	.000
	NP	.340	.024	10		

Table A.8: Comparison of gaze variables for inaccurate group in time pressure condition and no time pressure condition

Gaze Variable	Condition	M	SE	n	F	*p*
AP	TP	.038	.013	14	.119	.733
	NP	.031	.013	14		
BPN	TP	.021	.010	14	.000	.996
	NP	.021	.010	14		
IF	TP	.009	.005	14	.004	.951
	NP	.009	.005	14		
SN	TP	.150	.011	14	.000	.992
	NP	.150	.011	14		
OP	TP	.238	.024	14	3.869	.060
	NP	.306	.024	14		
P2N	TP	.238	.025	14	.002	.966
	NP	.239	.025	14		
SG	TP	.020	.008	14	.658	.425
	NP	.029	.008	14		
TT	TP	.859	.033	14	32.493	.000
	NP	1.125	.033	14		
EON	TP	.015	.006	14	.972	.333
	NP	.024	.006	14		
EOT	TP	.121	.035	14	11.151	.003
	NP	.288	.035	14		
TNT	TP	.136	.034	14	13.407	.001
	NP	.311	.034	14		