HEADS UP HOCKEY: TRAINING UPWARD GAZE WHILE STICK-HANDLING

by

Ben MacAskill

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ABSTRACT

A pilot study assessing an off-ice, computer-based training intervention (Quickstickz, QS) at improving upward gaze and on-ice performance. Elite male hockey players (n=10, age 11-12) were recruited. Participants were randomly separated into two groups. Following baseline testing in on-ice drills, one group received QS intervention, training for 30 minutes per day, 4 days a week for 4 weeks. After a second on-ice test, the remaining participants received the training intervention, followed by a final on-ice test. Due to drop out (n=10) the two groups were combined for pre-intervention to post-intervention analysis using paired t-tests. Results demonstrated a significant reduction in time to complete drills (mean±sd: pre: 119s±10s; post 110s±11s; p=0.03). Non-significant results from pre- to post-test for mean gaze-up angle (pre: $-10^{o}\pm38^{o}$; post $1^{o}\pm21^{o}$; p=0.45) and percent gaze-up (pre: 37%±27%; post 50%±25%: p=0.26). Power analysis indicated that significant results may be achieved with a sample size of 21-48 participants.

LIST OF ABBREVIATIONS USED

ANOVA – Analysis of Variance

BCHL – British Colombia Junior Hockey League

CSA – Canadian Standard Association

CT – Computed Tomography

GMP – Generalized Motor Program

GTHL – Greater Ontario Hockey League

MRI – Magnetic Resonance Imaging

NHL – National Hockey League

OHL – Ontario Hockey League

QS - Quickstickz

TBI – Traumatic Brain Injury

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Chapter 1: Introduction

A concussion is a type of traumatic brain injury (TBI), and is a complex, pathophysiological process affecting the brain, induced by traumatic biomechanical forces. It may include a loss of consciousness, neuropathological changes and neurological impairment that can be short-lived or sustained as post-concussion syndrome. Diagnosis is difficult, as Magnetic Resonance imaging (MRI) and Computed Tomography (CT) scans appear normal, even with cognitive, physical, emotional and behavioural changes. Current forms of concussion evaluation are varied, with most including tests of balance and gait, along with verbal or computerized tests of memory and cognitive abilities (38). Concussions in youth sports are particularly concerning, given that axonal injuries at a cellular level can have significant implications on working memory and behaviour (26). In recent years, concussions have garnered media attention and concern in the sports community. Although most concussions are highly underreported, the highest reported rates of TBI's, according to the national emergency department in the US, occurred in 10-14 year olds followed closely by 15-19 year olds (41).

Research into the causes and implications of concussions is also increasing. In one study, injury rates, risk factors and mechanisms of injury were investigated in minor hockey in Calgary, Alberta by implementing an injury surveillance system. Minor hockey players (age 9-16, n=986) were tracked during the 2004-2005 minor hockey season by athletic therapists for injuries that required medical attention, resulted in removal from a session, or missing any further on-ice sessions. Results showed a total of 216 players suffering 296 injuries over the season (just over 30 injuries per 100 players), with the most elite divisions in Peewee age group (11-12 years old) suffering the greatest risk. Deliberate body contact of an opponent with the puck resulted in 45% of injuries, with the most common being concussions at around 18-20% of total injuries. The majority of injuries occurred in the highest competitive level. Increased competition and speed at this level, as well as unfamiliarity with checking and disparities in size and strength all contribute to the high injury rate at this level (14,15,19).

A recent study evaluated the removal of body contact altogether in elite Peewee (11-12 year old) hockey players. The study compared 294 elite players in Alberta with 166 elite players in Ontario after the removal of body contact in Ontario during the 2011-2012 hockey season. In these elite players, allowing contact did not make a difference in concussion incidence rate ratio based on multiple regression analysis adjusted for clustering by team, exposure hours, level of play, position and body checking attitude. The incidence rate ratio was 1.22 for Alberta with Ontario as a reference (15). Even if removal of body contact resulted in decreased incidence of concussions, as it did with non-elite players in this study, as suggested by a high incidence rate ratio of 2.83, the following year players will enter into a contact game and will be unprepared. Delaying the process by a season does not necessarily solve the problem.

Other approaches to decreasing concussion rates in hockey involved changes to helmet design and alterations to rules and regulations such as increased penalization for direct hitting to the head. An investigation was conducted into injury reporting trends in the North American media, in which a qualitative analysis of newspaper articles published in the Chicago Tribune, New York Times, Toronto Star, and Vancouver Sun between 1985 and 2011 was performed (10). Key terms, such as head injury, concussion and brain trauma, were searched throughout articles pertaining to hockey through these years, resulted in 541 total articles. The number of articles published in each time period were as follows: 49 articles in 1985-1989; 185 articles in 1990-1999; 187 articles in 200-2009; and 120 articles in 2010-2011. The articles included perceived clinical severity of brain injuries and the dangers of repeat injury, the inability of equipment, including helmets, to prevent brain injury, the inability of rules and regulations to protect against brain injuries, as well as the importance of keeping hockey players safe (10).

The literature suggests that the focus on brain injury has increased over the past 30 years, and the mechanisms of injury continue to elude equipment and regulations (15). In a 1998-2000 prospective cohort study, a concussion history was obtained from the British Columbia Junior Hockey League (BCHL) in order to determine demographics, causes, treatment, and prevention to guide future recommendations on how to reduce injuries. The study included 272 minor hockey players (male and female, 5-16 years old) from 1998-1999, and 283 players (male and female, 5-16 years old) from 1999-2000. Over these two seasons, 379 concussions were reported, accounting for 18% of total injuries. The leading cause for concussions was the head striking the ice or boards after a collision. In the ages where body checking was allowed at this time (Peewee and Bantam, 11-14) there was a significantly increased risk of collision injury, found in the more elite divisions of play (15).

Body Contact in Youth Hockey

Hockey is structured in that players begin at the novice level (ages 5-8), increasing to the Atom level (9-10), on to Peewee (11-12), Bantam (13-14), Midget (15-17), Junior (16-20) and then University or Professional (18+). Players are introduced to body contact at the Bantam level, which has a major impact on the amount of injuries that occur (18). The puck is the focal point of the game, and the player who is in control of the puck is the main target for opposing players. Opposing players try to separate the puck from the player who is controlling it, which results in a requirement for the player with the puck to avoid them. A player can protect themselves from these opposing players only with knowledge that they are approaching.

Vision is important to identify approaching players and for guiding collision avoidance actions. Research suggests that vision is required for regulating limb guidance and placement during movement in humans regardless of athletic ability (5). As an example of the role of vision in obstacle-avoidance behaviour, a study involving 8 male varsity soccer players (18-23 years old) tested the ability to avoid an obstacle on a walkway versus an age and sex matched control group. The obstacle was mounted on a rotating arm, and was capable of producing random motion on the pathway at different levels of height. Participants, wearing a pair of liquid crystal display goggles that were able to occlude vision temporarily, were to walk a track and attempt to avoid the object. In one trial, vision was removed three steps before the obstacle and returned 1 step before the obstacle. In another trial, vision was removed two steps before the obstacle and returned one step after the obstacle. A control trial was also included that involved full vision throughout the trial. Dependent measures were calculated using a visual 3D program, including velocity, take off distance, lead foot landing distance, and peak trail and lead toe elevations. Behavior only differed in full vision control trials, where peak trail toe elevation resulted in a main effect between groups, with greater values only showing up in the full vision trials for the control group. The results suggest an advantage for the soccer athletes but only when continuous vision is available, suggesting that visual processing is a key component of the avoidance skills in athletes (5). In relation to hockey and risk of concussion, the capability to avoid collisions and potentially TBIs presumably depends on using vision to scan the environment in addition to other skills such as handling the puck.

Gaze refers to the direction of the eyes in relation to the external world, reflecting the combination of head and eye position and thereby impacting the availability of precise visual information from the fovea of the retina (34). The focus of gaze is correlated with the focus of attention, such that objects that are gazed upon are more likely to be processed at a high level and thus influence decision-making and overt behaviour (34). In hockey, and other sports, there is a competition for the participant's gaze between object-manipulation tasks (i.e., handling the puck; a task taking place in the lower visual field) and locomotor tasks (i.e., navigating the playing surface and avoiding obstacles; a task depending upon the middle and upper visual fields), since these tasks occupy very different areas of the vertical visual axis. In hockey, the visual identification of opponents on the ice depends on the gaze direction and angle. Avoiding collisions with opponents can be likened to the objects in the walking path of the soccer players in the previous study (5). Given that gaze is likely important for avoiding collisions, and that the player controlling the puck is the primary target for physical contact, it is important to determine to what extent new players can acquire the ability to keep their gaze on the environment while also controlling the puck at the same time.

Learning a new skill, such as handling the puck with the hockey stick, involves advancement through different stages of learning, with the initial stages depending on continuous visual monitoring and concentrated attention (34). Specifically, youth hockey players in the novice or intermediate phases will tend to gaze downward at the stick and puck, making it difficult to deviate the gaze upward to monitor for and avoid collisions. Controlling the puck and avoiding collisions can be thus be considered a dual-task scenario. Research on dual-task performance suggests that errors in a primary task increase with the introduction of a second task in novice performers but not in experts. A dual-task study of baseball performance included 10 expert batters (15.7 years of competition) and 10 novice hitters (2.3 years of competition), and they would swing a baseball bat at a simulated baseball while performing an auditory discrimination task. Results suggested that experts and novices react differently to the introduction of secondary tasks due to devotion of attention, as experts were largely unaffected (4). One interpretation of this finding is that experts require less attention to perform tasks in their domain of expertise, and can thus allocate attention to other secondary tasks without suffering performance costs. In the context of hockey, this observation suggests that developing expertise in puck-handling skills may allow the player to devote their gaze, and attention, to the task of avoiding opposing players and thereby reducing the risk of a TBI.

In support of the importance of monitoring for potential collisions, there is evidence that the severity of collisions is reduced when hockey players successfully anticipate physical contact from opposing players. One study followed sixteen hockey players (14±0.5 years) wearing specially designed helmets to measure linear and rotational acceleration for head impact severity over a 54 game season to determine differences in severity between anticipated collisions and non-anticipated collisions (27).

A Head Impact Telemetry (HIT) system composed of 6 single-axis accelerometers positioned inside a helmet and a remote data collection system, was used to measure accelerations resulting from impact. Video of the puck carrier during the games were used in conjunction with a check list of standard evaluations of observable body positions prior to and during collisions to determine the level of anticipation for each hit. Good body position on this list equated with anticipated collisions, and at minimum, the player had to see the hit coming, and had braced with knees in flexion and shoulder width apart, and used his legs to drive his shoulder into the collision. Poor body position, (poor anticipation), was where a player saw the hit coming but did not brace for the hit. Unanticipated collisions were those in which the player did not see or brace for the collision. Body collision type and level of anticipation were separate independent variables. Only head impacts of greater than 10 G were included. Hit severity was analyzed based on a weighted composite score including linear and rotational accelerations, impact duration, and impact location (along the boards or near the middle of the ice, where middle of the ice hits resulted in higher head impacts). Analyses of high (top 25% severity) and low intensity (bottom 50%) resulted in no significant differences based on anticipation level. However, in analyses of medium intensity head impacts (50-75%), anticipated collisions (15.2 [95% CI: 15.0–15.5]) and even poorly anticipated collisions (15.3 [95% CI: 15.1–15.5]) resulted in significantly less severe head impacts at $p<0.05$ than unanticipated collisions (15.6 [95% CI: 15.3–15.9]) (27). Increased awareness and anticipation of hits leads to decreased hits received and decreased impact force.

Training Upward Gaze

A case can be made for the importance of training young hockey players to learn to control the puck while maintaining a relatively upwards gaze angle so that they can better see, and thus avoid, traumatic collisions. A training program of this type would provide a proactive approach to reducing concussion frequency and severity, in addition to other injuries resulting from physical contact. Evaluating the efficacy of such a program, in terms of monitoring collisions and injuries but also the direction of gaze, provides considerable practical challenges. A gaze tracking camera would need to be installed inside the helmet, which, with current commercial technology is not feasible as wireless cameras tend to be bulkier for battery and screen size. The helmet including the camera would also need to pass safety regulations for gameplay, and a large sample of data would be required to reliably detect injury rates and severity. A reasonable alternative given the equipment and ethical and safety constraints is to study gaze and puck-handling performance in a more controlled environment. Given ethical concerns with introducing physical collisions and potential injury, a preliminary approach might be to simply monitor the capability to maintain an upward gaze angle while maintaining a good level of performance in puck-handling tasks similar to those required during game play.

There is considerable support for the notion that for young players acquiring a skill, a dynamical system approach by interacting in game situations and learning solutions on their own through making mistakes is better than the traditional motor pattern learner approach (practicing or repeating one skill) (11). For example, in football, learning and skill development arises not from repetition of one-dimensional movement patterns, but rather from an interaction and adaptation to the specific demands of the task or game being played. Players that are able to practice at home may be advantaged in that they have this opportunity to learn and discover techniques on their own that they can then apply to game situations. For hockey, the best training environment would be on the ice in an actual rink, following this dynamical systems approach. However, ice time is limited and costly for individual players who need more practice (28), so a home-based training program would provide considerable practical advantages.

Video-game training is one possibility for a fun, home-based training solution. Evidence for the efficacy of hockey-specific video game training applications is lacking However, there are some studies that demonstrate in a general way that computer-based training programs can lead to benefits in untrained tasks that mimic real-world cognitive tasks (21). Research has suggested that action video games are capable of improving a range of visual and attention skills. The video game would need to target both puck-handling skills and upward gaze angle at the same time, representing a dual-task situation.

Recent evidence suggests that improvements in dual-task performance are unlikely to occur from practice of the single tasks in isolation, and might depend upon specific practice of both tasks concurrently as is required in the real dual-task context. This relates to the tasks of controlling a puck while keeping the gaze in an upward direction. For example, a video game experiment involving 60 older adults (33 male, 27 female) and 18 younger adults (9 male, 9 female) using a game known as NeuroRacer, involved the primary task of steering a car through a track and the secondary task of identifying via a button press signs that intermittently appeared on the screen (21). The experimental groups were: a) single task training, where participants were trained on steering and sign identification separately; b) multiple task training, in which the participant would have to steer and identify signs simultaneously; and c) a no-contact control, in which participants did nothing as far as gameplay. A cost index was calculated based on the number of correct sign identifications and the number of false alarms, as well as the amount of time spent on the road, to determine improvements in multitasking performance. Improvements in the cost index, indicated by a less negative percent of cost (-64.2% pre-training to -16.2% post-training) were observed for working memory and sustained attention in only the multiple tasks group (21). These results suggest that training the ability to maintain the gaze in an upward direction while controlling the puck must be performed simultaneously.

The knowledge that training multiple tasks at once can benefit dual-task performance provides benefits for a hockey video game training device, as the game could be modeled around key elements of actual gameplay. The intervention could then be an off-ice, home-based video game training involving controlling the puck while being aware of what is happening on screen and reacting to it.

Quickstickz

Quickstickz is a video game developed to teach hockey players to keep their head up in order to observe their environment while stickhandling. The Quickstickz training system includes a stickhandling ball with video sensors and a tracking device that attaches to a display screen to enable a virtual display of the ball while it is moved using a hockey stick on the ground. The game requires the player to move the virtual ball through targets shown on the display screen, thus requiring the player to keep their gaze up on the display screen while performing a ball manipulation task on the ground below without diverting the gaze downward. The basic premise is that this dual-task training approach may promote an increased capability to handle the puck on the ice during real games, while keeping gaze in an upwards position to monitor for potential collisions. To date, no studies have been conducted to test any of these claims. The purpose of the present study is to evaluate whether training with the Quickstickz game can lead to improvements in upwards gaze angle during on-ice hockey drills.

This study is not directly a concussion or injury prevention study, rather it is a study implemented as a proof of concept study to see if Quickstickz training might lead to increased upwards gaze time during actual on-ice play. There is support that anticipation of a hit is a major factor in whether or not this hit causes an injury, and having the head up to see other players approaching allows a player to anticipate (27). Brain injuries have become one of the most common injuries in hockey. Where retroactive techniques such as equipment development and rule changes have failed to keep players safe, teaching players to control the puck with their head up at a young age, to the point where it is automatic and requires little or no visual feedback allowing attention to be directed upward to the environment, could be a proactive solution to prevent further injuries. This study is the first effort toward exploring if upward gaze can be acquired using an off-ice video game training system.

Hypotheses

The Quickstickz game is designed to promote stickhandling skills in hockey players, and to encourage upwards gaze when doing so. Although there is no existing evidence to support either of these claims, the nature of gameplay suggests that learning and transfer from off-ice training to on-ice performance could occur. As such, it is hypothesized that a 4-week intervention with the Quickstickz game will lead to improvements in on-ice hockey drill performance reflected in reduced time to perform the drills. More importantly, it is predicted that Quickstickz training will lead to an increase in the percentage of time spent during on-ice drills with the gaze in an upward direction. Relatedly, it is hypothesized that the average gaze angle throughout the on-ice drills will be more upwards than prior to the intervention.

CHAPTER 2: LITERATURE REVIEW

The main interest of the study is to reduce injuries and concussions in hockey. It is possible that the best approach to this issue is to provide a means of training contact avoidance through improved visual behavior. Hockey is the unofficial national sport of Canada, with close to 900,000 5-17 year olds registered in minor hockey in 2014 (15). In Novice, players begin to learn basic fundamentals of skating and controlling the puck. The skills and abilities required for success progress as players get older, bigger and stronger, and each age groups begins to be divided into separate teams by ability. The elite groups, typically denoted as 'AAA', are the teams with the top players in each respective age category. Skating speed, anticipation of play, coordination in controlling the puck, and the ability to perform all these tasks at one time allow players to perform at a high level. As players become bigger, faster and stronger, and the game becomes more competitive as body contact is introduced (currently at the Bantam level), the number of injuries and concussions begins to increase. During the 2007-2008 hockey season in Alberta, concussion was the most common injury with a rate of 1.47/1000 player-hours (14). Concussions have recently been prevalent in the media, making them a major social issue (10).

A direct blow to the head or face, or even contact with the body so long as an impulsive force is delivered to the head, can cause a concussion. In most cases, impaired neurological function begins immediately and gradually resolves within minutes to hours. The most severe impairment is found at the first day following the concussion, but symptoms may last for weeks or months (19). These clinical symptoms, including cognitive, behavioural, emotional and physical disturbances, often reflect functional issues rather than structural injury. This means that neuroimaging measures such as MRI and CT scans do not reveal abnormalities. Standardized testing to assess concussions is yet to be agreed upon, however the performance of patients with concussion symptoms has been found to decline on computerized tests of simple, choice and complex reaction times when compared to a control group (8,9). Currently, attention and executive functions including mental processing speed are the areas most often assessed following concussion. Motor performance and gait are also affected, and current research is directed toward assessing baseline values of cognitive skills and balance together (23).

Injury Reduction Strategies

As research on proper assessment of concussion advances, the literature on prevention strategies falls short. Current approaches in preventing head injuries include regulation and policy changes, including shifting the age that body contact is introduced. Prior to 2011, body contact was introduced at the Peewee level. A policy change after that year eliminated body contact at the Peewee level, delaying the introduction of contact to the Bantam level. A cohort study conducted during the 2011-2012 season compared 294 elite players in Alberta with 166 elite players in Ontario after the removal of body contact in Ontario. When factoring in team, exposure hours, level of play, position and body checking attitude, the concussion incidence rate ratio was 1.22 for elite divisions and 2.83 for non-elite players in Alberta, with Ontario as a reference (2). Although removal of body contact resulted in decreased incidence of concussions in non-elite players in this study, the elite players experience little or no change at all.

Along with policy changes in minor hockey, attempts to decrease the rising rates of concussion also included changing the rules of the game. In 2010-2011, officials were instructed to penalize all forms of head contact, adding an extra 10 minutes to the former 2-minute penalty. Increased suspension for more serious contact was also implemented. A retrospective cross-sectional analysis of 2211 National Hockey League (NHL) and Ontario Hockey League (OHL) players (all male, ages 16-20 in OHL, and ages 18-43 in NHL) was completed over three seasons (2009-2012). Data collection included penalties called during a randomly selected ten-week period. Concussions and suspected concussion history data were also collected through a variety of sports media sources. One- and two-way analysis of variance (ANOVA) with post-hoc comparisons using Bonferroni corrections were used to determine changes over the three seasons analyzed. Determining risk factors for concussions was completed through stepwise logistic regression, taking several risk factors into account (age, height, weight, position, experience, fights, statistics, penalty minutes, suspensions, and games played). The number of concussions versus suspected concussions did not change over the three seasons studied (1-way ANOVA, $p>0.05$). The results suggest that rules regulating body contact to the head did not reduce the number of players experiencing concussions (12).

Policy and rule changes are not the only approach. Alterations to equipment have also failed to reduce injury and concussion risk. Increasing helmet size and changing the design, as well as investigating facial protection measures have been attempted. Many studies have looked at the difference in concussion rates when players wore a visor (protects upper half of the face) versus full facial protection. However, in minor hockey, full facial protection is mandated. It is suggested in the literature that the use of helmets with full facial protection has eliminated eye, face, dental and extracranial head injuries, but brain injuries remain a serious concern. The reason being that with increased protective gear arises an associated increase in the level of aggressive play, which in turn increases the incidence of concussions (19). Even increasing helmet size has led to speculation that the added mass and area of a helmet and full face shield may increase the rotational acceleration of the head following impact, producing greater shearing forces on the brain, and increased severity of concussion (6).

Current measures discussed to eliminate concussions in players all involve alterations to sources external to the players themselves. The opposite approach would be to investigate and influence forces internal to the players. Teaching them to avoid contact with opponents could be done through developing the ability to anticipate a collision and reduce their injury risk. In order to develop anticipation abilities, vision must first be trained in players while they are controlling the puck to allow them to see incoming opponents so that they can react and avoid contact. These concepts will be discussed further in the following sections.

Improving Gaze

Anticipation

Anticipation in hockey is the ability to predict what will happen next in a given situation on the ice. In regards to contact avoidance, visual feedback and previous experiences allow a player to anticipate where an opponent is heading, in order for them to avoid contact with that opponent (20). Visually identifying the opponent is key for this anticipation to occur, as visual identification directs the player's attention to the opponent. This process is referred to as gaze. A player must be able to direct their gaze towards the opponent in order to visually identify and select an appropriate response (i.e., avoidance tactic). The problem is that the player who is controlling the puck during a game is the target for opposing players, and it is a difficult skill to control the puck while maintaining an upward gaze at the same time.

There is support that anticipatory skill can be enhanced with practice. One study supporting this claim included 15 male and 15 female participants (age 16-28 years old) that were initially tested on visual functioning and anticipatory skill in racquet sports. They were assigned to three equal groups: a perceptual training group, a placebo group and a control group. The perceptual training group performed four 20-minute sessions of supervised perceptual training and one 20-minute session of motor practice each week. Perceptual training included formal instructions on racquet stroke, as well as how to locate the most important cues for information on where the ball was going. Differences in the way experts and novices use the information was also explained, along with video examples. Practice included simulated motor responses to certain game film, predicting stroke direction and force from spatially occluded displays, or making anticipatory predictions by pausing the video to vary the temporal occlusion stress imposed. The motor practice session consisted of continuous hitting forehand strokes while moving or stationary, to balls projected from a serving machine. Participants in the placebo group read material and watched videos on racquet sports, as well as participated in all practice sessions. The control group only undertook the physical practice session each week, without feedback. Percentage of errors in predicting stroke direction and depth were assessed from the anticipation test, using three-way analysis of variance (factors of group, test occasion and temporal occlusion level). The main finding was a significant Group by Test Occasion interaction, $F(2, 25) = 18.939$, $p < .001$. Given specific anticipatory training, participants were able to accurately predict outcomes, indicating that anticipation training in this manner and design was effective in improving player anticipation in the racquet sports (1).

Anticipating ball movement and trajectory is different than predicting opponent movement on the ice, which is more dynamic. That being said, both sports require visual identification and directed attention toward the object, regardless if it is a ball or an approaching opponent. In order for these processes to occur, and to initiate the anticipatory response, the gaze must be directed in the right place.

Target Age

In minor hockey in Canada, body contact is introduced at the age of 13, so players should learn anticipatory responses and to maintain the appropriate direction of gaze by the critical age of 12 years old, before the risk of injury rises. In a 1998-2000 prospective cohort study, a concussion history was obtained from the British Columbia Junior Hockey League in order to determine demographics, causes, treatment, and prevention to guide future recommendations on how to reduce injuries (15). In the ages where body checking was allowed at this time (Peewee and Bantam, 11-14) there was a significantly increased risk of collision injury, found in the more elite divisions of play (18). Data from another study in British Colombia around the same time, using injury reports as well as retrospective surveys from minor hockey players, suggested under-reporting of concussions, especially in the 12-17 age groups. These studies emphasize the importance of learning to direct the gaze-up very early on.

Task Analysis

Motor Skills and Control

It is important to review the basis and progression of skill development to better understand when and how to train stickhandling and gaze behaviour, and what to expect at different stages of expertise. Movements can be classified into discrete, continuous, and serial skills. A skill is the ability to bring an end result with maximum certainty and minimum use of time and energy (34). Discrete skills have a distinct beginning and end (e.g., shooting a puck), while continuous skills have no recognizable beginning or end and can continue until stopped at an arbitrary point (e.g., skating). Serial skills are a series of movements blended together to make up a whole action. Team sport skills are usually serial skills, as the order and timing of actions are important to produce skilful movement, such as skating while passing or shooting a puck. Motor control requires the integration of sensory information in the brain to control and direct movement processes through coordination of muscular contractions in a sequential manner. Memory structures specify muscle activation, relative force levels, and relative timing, all of which encodes how to make a particular movement pattern, which can be encoded as a generalized motor program (GMP). This is a set of muscle commands that are structured before a movement begins, and that allow an entire sequence to be carried out. This process enables learning to occur, as it is a form of memory and is responsive to feedback so it can change with experience. Therefore, learning a skill requires experience and feedback to form motor programs and patterns (34).

Developing specific skills in hockey progresses as players practice, play and gain experience. As hockey is a dynamic, fast team sport involving many players on the ice at one time, many skills must be performed at once. Controlling the puck with the stick and skating are two of these specific skills that must be combined in order to be successful. Since skating indicates that the player is moving, they must also be able to know where they are heading. This involves maintaining an upward gaze while they are controlling the puck. The progression and development of controlling the puck can be described by the three stages in the multi stage theory of learning: the cognitive phase, the associative phase, and the autonomous phase (17).

The cognitive phase is the phase in which the learner attempts to perform the movements required for the action. This phase requires a large devotion of cognitive resources, so that strategies can be developed to bring the movements closer to the desired actions. Performance is inconsistent yet the largest gains are made in this phase. The use of feedback strategies is very effective in this phase, as it is coined the verbal-motor phase. This stage would reflect hockey players at the novice level, from the first time they pick up a stick. They know that they have to move the puck around, but they will need to be taught how to do this, as well as begin to develop the motor patterns such as where to place the hands, how to coordinate movements for the desired actions.

The associative phase consists of small gains after the learner has developed the most effective way of performing the task. The movements become more consistent, and verbal aspects fall off as the learner becomes more concerned with how to do the particular task rather than what pattern of action should be produced. It is often referred to as the motor stage. The task of controlling the puck would involve moving the puck around in different patterns, so a child in the associative stage would already have acquired the basic motor patterns of controlling the puck, but will now be focused on how to perform specific movements.

After many months or years of practice, the task becomes automatic to the learner, and can be performed with less interference from other simultaneous activities (34). This stage is known as the autonomous stage. Experts in particular skills are able to perform their activities in the autonomous phase, as they have been practicing all their life. The most highly skilled players can handle a puck as if the stick was an extension of their hands, and they rarely have to look down for visual feedback or think about what they are doing. Many professional hockey players have this ability, however not all players are required to perform in the autonomous stage for puck control skills. Certain players are assigned roles on a team, and as such, require different skill sets. There is a wide range of skills involved in hockey, including skating, puck control, passing, and anticipation. In some cases, a player may be a great skater, and is able to participate at the highest level of play, but does not have expert puck control skills.

Open and Closed Skills

There are two different processes concerning skilled movements that can be related to controlling a puck in hockey. Closed-loop movements require feedback, as proprioceptive, auditory, and most importantly, visual feedback all affect the movements that a player will make while handling the puck in terms of which direction they go, how fast they handle the puck, and which patterns they choose to execute. This closed loop form of handling the puck would occur during practice, while the player is in a static environment. Open-loop skills are those skills performed in dynamic, unpredictable environments. An example of an open loop process is a player controlling the puck during a game, while having to respond and react to the ever-changing on-ice environment (34). More recently, motor research has shown interactions between feedback (i.e., closed-loop) processes and open-loop processes.

There are three stages of motor control in which the action can be categorized, and functions of feedback in the control of movement occur in correlation with these movements. The stages include: before the movement occurs; during the movement; and after the movement. Before the movement, sensory information provides cues for the initial conditions of the movement. The motor system must know these initial conditions of the body so that it knows where to move the limbs in relation to its initial condition to achieve the goal. In hockey, the initial conditions are usually the hockey stance, with knees bent, head up, and stick on the ice. There are many factors to take into account, such as force and velocity of movement, movement angles, and coordination with other limbs, especially if the player is already moving. The motor system is able to predict and control all of these factors (34).

During the movement, feedback is used to monitor the movements and alert the system when something goes wrong, or when an action fails to parallel the goal of the system. For example, before the movement, the player may decide to handle the puck at a comfortable speed, with the puck out in front of the body. The initial conditions report that the player is in the hockey stance, and before the movement occurs, the action plan is to stickhandle the puck in this manner. Feedback is ignored if nothing goes wrong, but attention is directed to the area and corrections can be made if there is an error (34). In this case, if the player loses the puck because they did not lift the stick blade high enough, the feedback from mechanoreceptors deriving from the decreased weight on the blade of the stick, and the visual feedback from noticing the puck slip away, is evaluated and can be used to help carry out the next movement in a smoother, more accurate manner. This is very important in the acquisition and development of skills through practice.

Dual-task Performance in Sports

Research on dual-task performance suggest that improving the ability to control the puck and maintaining an upward gaze can allow a player to divert their attention elsewhere on the ice. Results from a study on the effects of attention to external information and primary skill execution in baseball suggested that errors were increased with the introduction of a second task in novice performers but not experts (4). Participants included 10 expert batters (15.7 years of competition) and 10 novice hitters (2.3 years of competition), and they would swing a baseball bat at a simulated baseball while performing an auditory discrimination task. Results suggested that experts and novices react differently to the introduction of secondary tasks due to devotion of attention, as experts were largely unaffected. This study answers some questions involving the processing and completion of peripheral tasks while maintaining attention and focus on another task (4). The experts in this study are playing in the autonomous phase. In Hockey, stick-handling can become automatic to players and they can focus their vision and attention on the environment in order to see teammates and opponents location, and decide what actions they will perform. Novice or intermediate players that have not yet reached automaticity rely more on vision for feedback, and they tend to look down at the puck while stickhandling. This is a detriment to their ability to see the ice and the other players around them.

Specificity of practice is the theory that transfer is more likely when the practiced and target tasks share more features or elements (34). That is, improvements are specific to the source or sources of sensory information that optimize performance during practice (32). If a player can reliably depend on other sources of sensory information, mainly proprioceptive information such as the movement of the arms, wrists and hands, as well as the weight of the puck on the blade of the stick and perhaps the peripheral visual field to see the puck below them, they may be able to free their visual stream so they can scan the ice for opponents.

Optimal Practice

The best practice is actual game-play itself, but ice time is in high demand and low supply for many reasons. For one, ice time is expensive. In Sudbury, Ontario, for example, rental rates rose to around 200-250 for one hour in 2015. The Greater Toronto Hockey League (GTHL), which is the minor hockey association in the greater Toronto area, had an annual ice time budget of 4.8 million dollars (28). Also, the majority of ice time that players have access to includes team-based practices and games. For development, Hockey Canada recommends a ratio of 2 practices to 1 game, because during a game, players only have the puck on their stick for an average of 8 seconds per game (29). Even during team practices, with 20 or more players on the ice at one time, typical coaching mentality is structure and organization for the whole team, to improve team play in hopes of winning games. Individual player development of certain skills, such as keeping the gaze up while controlling the puck, becomes largely ignored. Ken Dryden, a legendary hockey goalie and Canadian politician, wrote in his book “that it is in free time that the special player develops his abilities: not in the competitive expedience of games; in hour-long practices once a week; in mechanical devotion to packaged, processed, coaching-manual, hockey-school skills" (13).

This is why it is important to investigate ways to practice away from the rink, during the players' free time, which could successfully transfer on ice and in games. This concept is referred to as fidelity of training, and players could benefit from a way to train their ability to control the puck while maintaining an upward at home, so they can practice on their own time in a cost-effective way. Video game or computer-based training may be able to accomplish this. Players could improve their performance in the tasks presented by the game, but perhaps also a transfer task that more closely matches the target skill of handling a puck during competitive play.

It would be ideal to find current literature on video-game training for hockey skills, but no studies could be found. Although the design and basis are different, reviewing other video-game research that requires the brain to focus on more than one task at a time may help to support the theory of transfer of training. A video-game experiment involving 60 older adults (33 male, 27 female) and 18 younger adults (9 male, 9 female) using a game known as NeuroRacer, involved the primary task of steering a car through a track and the secondary task of identifying, via a button press, signs that intermittently appeared on the screen (2). The experimental groups were: a) single task training, where participants were trained on steering and sign identification separately; b) multiple task training, in which the participant would have to steer and identify signs simultaneously; and c) a no-contact control, in which participants did nothing as far as gameplay. A cost index was calculated based on the number of correct sign identifications and the number of false alarms, as well as the amount of time spent on the road, to determine improvements in multitasking performance. Improvements in the cost index, indicated by a less negative percent of cost (-64.2% pre-training to -16.2% post-training) were observed for working memory and sustained attention in only the multiple tasks group (2). Training individual tasks to make each better on their own does not lead to better multitasking performance. The multitask activities must be performed at the same time in order to improve performance. Thus, practicing controlling the puck on its own and then practicing keeping the gaze up on its own will not necessarily result in improved performance of both tasks together. These two tasks must be practiced simultaneously. A cognitive battery of tests was then administered to test cognitive abilities such as sustained attention, working memory, and basic motor and speed process. The results suggest that playing a video game with multitasking elements not only improves performance on the video game itself, but the improvements also transfer to tasks requiring working memory and sustained attention outside the video game (2). This indicates that transfer to new task contexts is possible, and fidelity of the training game might not matter as long as the key task elements are shared from training to the target task, and are performed at the same time. This would prove beneficial in a video game that specifically trains puck control and gaze-up, as these two task elements are shared from training to gameplay.

Learning and Transfer

Video-game training may only prove effective if the video game was structured more like an actual hockey game based on the principle of transfer of learning. The evidence for transfer of video-game training to other untrained tasks is mixed. A general cognition online training study was conducted over the course of six weeks, in which

11,430 participants trained several times each week on a variety of cognitive tasks including memory, planning, visuospatial skills and attention. The games include six training tasks of reasoning, planning, problem-solving abilities, and a broader range of cognitive functions, trained using tests of short-term memory, attention, visuospatial processing and math similar to those commonly found in commercially available brain training devices (31). Participants were to play these games for a minimum of 10 minutes a day, three times a week. Even though improvements were observed within the game itself, no evidence was found for transfer effects to untrained tasks. No evidence was found to support the belief that training cognitive function in healthy participants using computer games would transfer beyond those tasks that are actually being trained (31). So, in order for a video game training system such as Quickstickz to be effective, learning must take place and it must be able to transfer to tasks outside of just the video game itself, such as on-ice performance. The background environment displayed on the computer screen is the ice surface in a rink, complete with boards and glass. The obstacles used in the drills are moving hockey sticks, pylons and targets, which are all items that are used during real games or practices. Ideally, the training game would provide the opportunity for players to avoid opponents trying to make contact with them while handling the puck in a virtual reality environment. Since a game of this sort does not exist, it is reasonable to suggest that Quickstickz may provide a sufficient substitute given the current existing accessible technology.

Practice Structure

Structuring the practice schedule for a Quickstickz training intervention requires knowledge of motor learning principles. Motor learning includes the change in ability to act or react to a stimulus following a period of practice. Transfer is when performance on a training task is carried over to other tasks. Retention refers to the degree to which motor learning remains over time following practice. For retention and transfer, the optimal practice structure includes distributed practice, variable practice, and random practice. Distributed practice is where practice is divided into a number of shorter sessions over a longer period of time, and is a more effective method of learning compared to massed practice (longer and less frequent or numerous training sessions). The current Quickstickz study included a training design that followed distributed practice, with four 30-minute training sessions per week for a total of four weeks. Variable practice consists of the use of a training schedule structured in such a way that the learner is faced with different parameters of a single skill, such as numerous puck control patterns, rather than constantly repeating the same ones consecutively. Variable practice is an extension of contextual interference, in which a learning benefit occurs when the items to be learned are mixed up across training sessions. For example, a normal back and forth puck control pattern could be mixed with wider, slower motions or quicker, shorter motions. This was included in training as well, as many different combinations of drills involving many puck control patterns were included in the training sessions. Random practice is simply the performance of the different skills in a random order, to minimize repetitions of a certain skill (36). A training schedule structured with short sessions, different variations of puck control in the Quickstickz game, and randomly practicing each variation, should provide the optimum retention of puck control skills while maintaining upward gaze and transferring to on-ice performance. Participants are also granted free time to play any drills they wish, to assist in the minimization of repetition.

Gaze Training in Sports

There is no existing research on gaze training in hockey, but it has been attempted in other sports. One study was performed involving volleyball players, and measures of gaze and reaction times. A preparatory study was set to identify appropriate visual cues for life-size displays that were to be used in the main study. This was done through the use of an eye-tracking camera (EyeSeeCam) and the viewing of volleyball practice situations on a life-sized screen. Participants for this preparatory study included 4 groups of 10 students (20-22 years old: 21 male, 19 female). The task during the video was to decide whether the player in the front or the player in the back would receive the ball in each scene by pressing a button as fast and accurately as possible. In one out of every three scenes, the hip of the receiving player was marked with a visual cue two frames after the ball had left the proceeding players' forearms. The visual cues were small/static, small/flashing, large/static, or large/flashing. The results from the preparatory study illustrate that when applying gaze path cues in a decision-making task, participants decide faster and more accurately. Also, the fastest decisions were in response to the large/static markers. It was also noted that after only a few cue trials, participants began to adapt their gaze strategy (24).

The main study investigated a real-life situation where the defending player in beach volleyball had to react to the spike of an opponent on the full size video screen. Participants (22 male, 23 female, age 20-22 years old) were divided into 3 groups: 3-group design with a functional cue group (expert's gaze path), a dysfunctional cue group (deviating gaze path), and a control group (simple verbal instruction). The task for each defender was to respond to one of three options that would be presented on the video screen, requiring them to keep their position against a shot, or to run forward to the right or left depending on the direction of the shot. For the cued scenes, either a functional (cue markers following a gaze path that expert players followed in previous studies) or a dysfunctional gaze path (cue markers followed trajectory of the ball only) was highlighted by large, static, red cues. The control group was not cued but was offered verbal instruction. Participants were tested pre-, post-, and on a retention test. Based on the gaze analysis, learning effects occurred for the dysfunctional group only, and all groups improved regarding decision-making. Gaze-cueing effect influenced gaze behavior in the expected way, but it was not optimal in improving decision-making skills (24). Although the assumptions that perception is enhanced with improved gaze behavior and that gaze improvements enhance perception are not supported by the results, they do suggest that gaze path cueing induces gaze changes in both immediate and more permanent ways.

Assessing Performance

The ideal assessment of performance in hockey would involve an eye-tracking system for players to wear during actual games, with an investigation into the relationship between concussion rates and gaze angles before and after a training intervention. In order for this to work, a wireless gaze tracking camera that is capable of being worn during games without compromising safety or inhibiting movement in any way would need to be installed inside the helmet. Limitations in current commercial wireless camera technology, such as the size of the cameras and battery requirements, create problems.

For Hockey Canada sanctioned games, helmets must also pass Canadian Standards Association (CSA) approval for safety. It is doubtful that a helmet with a camera facing an eyeball would be safe to wear during a game in which contact is possible.

The reasonable approach given the equipment and ethical and safety constraints is to study gaze and drill performance during a controlled practice environment. Drills that include body contact could result in injury as well, creating ethical concerns. Given the situation, assessment drills should involve various skills and movements that are similar to those performed in gameplay, in order to best replicate gameplay. For example, a study involving senior futsol (a modified version of soccer) players, participants performed a passing drill in one of four different conditions. Each condition had a different amount of task constraint involved, by increasing the number of possibilities for passing actions. Ball speed and passing accuracy were measured by video analysis in each form of the drill and during games. Results suggested that performance when more passing options were available related more closely to the competitive performance environment. It is also suggested that in order to achieve a high transfer between practice tasks and performance during the learning of a skill, it is important to maintain similar task conditions that allow players to act adaptively and to maintain action fidelity in competition (37). Many of the drills performed in Quicksticz require quick reactions to targets and obstacles with unpredictable locations. The number of possibilities helps to improve this adaptive reaction in hockey much the same as the soccer drills.

Study Design

The choice of sample size for the present investigation was challenging for several reasons given the exploratory nature of the research. No studies using the

Quickstickz training system have been conducted to date so there is no established protocol for training time or intensity, nor any estimate of a training effect size. Due to uncertainties, guidance for sample size was taken from related training studies that employed computer-based tasks in 16 participants (21). Sample size was increased to 20 participants as players were to be recruited from the same team, which would ensure that all players received the same amount of external practice and game time. It would also ensure that all players from the team were offered the opportunity to participate in the study.

The study was originally designed as a wait-list control trial based on the fact that only 10 Quickstickz units were available for the duration of the project. A wait-list design, where a group of participants would serve as a control during one phase of the study and then undergo intervention training in another phase would allow all participants to take part in the intervention portion of the study. The intervention period was set at 4 weeks, with participants training 4 times a week for 30 minutes per session. The intervention schedule was based on previous research that assessed the efficacy of computer-based intervention training, consisting of 16 sessions across a 4-week period, on the ability to improve anticipation in racquet sport. (1). The results of this study indicated evidence that anticipation assessed by their standardized laboratory procedures can be enhanced with practice, indicating that it would be a good training schedule to use as a model.

Most research involving gaze analysis place importance on gaze path and direct viewing of a select object, such as the Volleyball study discussed earlier, which includes both horizontal and vertical analyses (24). The main goal of the gaze analysis in this study was to determine if participants were looking up at the environment or down at the puck, so the vertical component of gaze was the only value of interest. Hence, the choice of dependant measures included percentage of time spent with the gaze in an upwards direction above the horizontal, average gaze angle, and time to complete the drills. Measuring the percentage of time with the gaze above horizontal versus below in a percentage value, as well as the average gaze angle, would allow for a reasonable extraction of improvement in gaze direction before and after a training intervention. The reason for measuring time to complete each drill is to ensure that participants are not sacrificing speed or performance on the drills in order to keep their gaze up. It would be easy for a participant to perform the drill in a slow and methodical fashion in order to keep the gaze up, but as part of this study is to improve performance during on-ice tasks where speed is necessary, sacrificing speed would not suffice.

The drills chosen to estimate puck-handling skills were Hockey Canada standardized skill testing practice drills. The drills have not been measured or assessed quantitatively in prior investigations, but rather than creating new drills, the standardized testing drills from hockey's governing body in Canada were expected to suffice.

A novel gaze tracking system was developed for the study, using an adapted Go-Pro camera, an accelerometer and a gyrometer. The measurement properties of the device were unknown prior to initiating the investigation.

CHAPTER 3: METHODS AND PROCEDURES

Methods

All study procedures were approved by the Dalhousie University Research Ethics Board (Appendix A). This was a pilot project investigating the efficacy of an off-ice training intervention for promoting gaze-up hockey performance using the Quickstickz video game. The sample consisted of 20 male Peewee hockey players (age range: 11-12 years). Due to the limited number of Quickstickz units available for the study (10 units), a waitlist-control design was used with 10 participants randomly allocated to each group. Initially, the first group of ten participants received Quickstickz for a training intervention, and the other group served as a control during this time. After a second on-ice test, the second group received Quickstickz for a month of training with the first group serving as a control, followed by a final on-ice test. Outcome measures were gaze behaviour (gaze-up time, average gaze angle) during, and completion time for, a set of standard hockey puck-handling drills. Effect sizes for the between-group comparisons made at the first post-test can evaluate statistical power for future research. A within-group comparison was planned for the waitlist group across their intervention phase to further evaluate the efficacy of the intervention.

The research plan proceeded as noted above, but analytical plans changed due to a large and unforeseen number of dropouts. Instead of a between-groups comparison at the first post-test period, the two groups were combined to create pre- and post-intervention scores and analyzed using a single group within-subjects comparison. Consequently, there was no control group included in the assessment of the Quickstickz product's efficacy.

Participants

The choice of a suitable sample size for the present investigation was challenging for several reasons given the exploratory nature of the research. First, no studies using the Quickstickz training system have been conducted to date so there is no established protocol for training time or intensity, nor any estimate of a training effect size. Second, a novel gaze-tracking system was developed for the study, so the measurement properties were unknown prior to initiating the investigation. Third, the drills chosen to estimate puck-handling skills have not been measured or assessed quantitatively in prior investigations. Due to these considerable uncertainties, guidance for sample size was taken from related video-game training studies which assessed 16 participants (2).

The recruitment pool consisted of a convenience sample of 20 male Peewee hockey players (11-12 years) from a single team in a minor hockey association in the Halifax region of Nova Scotia. Male players were chosen to reduce heterogeneity in the experimental groups for calculations of effect size. It can also be noted that body checking is not allowed in the female game. Although female participants might experience a performance benefit from increased ability to keep their gaze up, this study focused more on the contact-avoidance element which is less relevant in women's hockey. The sample size of 20 participants was greater than the target size of 16 participants as noted above, because it represented the total number of players on the selected team. Recruiting the players from the same elite team ensured that all players received the same amount of external practice and game time, and also ensured that all players from the team were offered the opportunity to participate. Recruitment letters were sent to email contacts found online for elite Peewee coaches in the area (Appendix B). The first coach to respond with interest was then sent a recruitment letter to send out to parents of the team and the players themselves (Appendix C). The recruitment letter requested that parents contact the principal investigator directly through email to express interest in participation. Once contacted, the principal investigator sent out consent forms, instructions, and dates concerning on-ice testing.

The consent process took place prior to the initial on-ice testing session, where procedures and consent, including rights and roles as a participant in the study, were explained to all participants and parents. They were given an opportunity and encouraged to ask questions about the process, and after reading through the form, they were asked to sign prior to taking part in the study.

Drop-out

The study began with 20 participants, assigned using a random number generator, to one of two groups (early intervention or late intervention group). Three participants withdrew before the initial baseline testing, realizing that they could not attend the initial baseline testing session after initially committing, bringing the total participant number to 17. Three participants also withdrew before the first post-test, leaving a total of 14 participants (see Table 1). The three participants who withdrew at this stage reported problems and frustration with Quickstickz technology as the reason for drop-out. An additional four participants withdrew before the final post-test, leaving only ten of the original twenty participants with a complete set of data. The main reason cited for withdrawal between the first and second post-test was that data collection commenced too late into the hockey season. Verbal reasons were given concerning these dropouts, all of which stated that with the transition into the summer months, different sports and activities were creating busier schedules, and they were no longer able to take part in the trials. The numbers of participants included in each statistical analysis are outlined and justified in the results section.

Table 1.
Number of Participants to complete testing at each phase of study.

	Intervention First (n)	Intervention Second (n)
Randomized to group	10	10
Baseline	8	9
Post-phase1	7	7
Post-phase2	6	4

Materials

Outcome Measures

Outcome measures were obtained from standardized on-ice drills obtained from Hockey Canada. All on-ice testing drills are depicted in Figure 1, and can be found at (http://www.hockeycanada.ca/en-ca/Hockey-Programs/Players/Skills-Testing/Test-Stations) or viewed as a video at (https://www.youtube.com/watch?v=GxsWuTQQzi4). Orange marker pucks were used in place of cones as drill markers on the ice. All participants wore a full set of their own individual hockey equipment, including stick, helmet, gloves, skate, pants, shin pads, shoulder pads, elbow pads, and cups. The participants used pucks to maneuver around the orange markers in different drills. A stopwatch (iPhone application) was used to measure time to complete each drill. In order to ensure consistency of drill performance times, participants were required to repeat any drill that was not performed correctly; in this case, the stopwatch was reset and the prior attempt was not recorded. A restart was required if a player fell or lost control of the puck and had to chase it down to retrieve it, based on the judgment of the investigator.

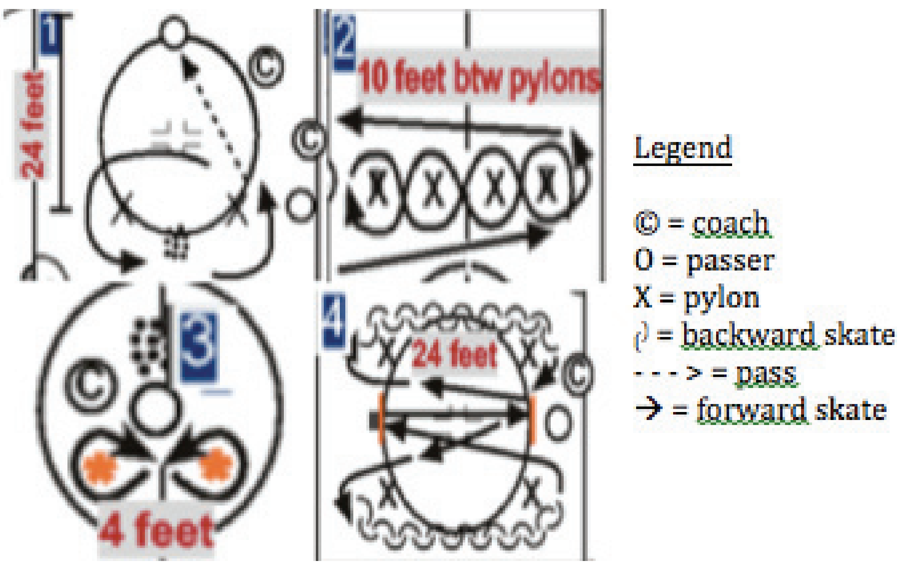


Figure 1. Pre- and Post-test drills to test skills as developed by Hockey Canada. To see these drills as videos: https://www.youtube.com/watch?v=GxsWuTQQzi4

A custom-made eye-tracking device was mounted to each player's helmet during drills. The device consisted of a GoPro Hero 3+ Black Edition camera (gopro.com), shown in Figure 2a, mounted with an extender to the cage of the helmet (2e). The camera was modified for optimal pupil tracking using a new lens (2b), infrared filter (2c), and infrared light source (2d), to produce a clear image of the pupil (2e) for off-line analysis of pupil position and transformation to eye-in-head angle (2f)

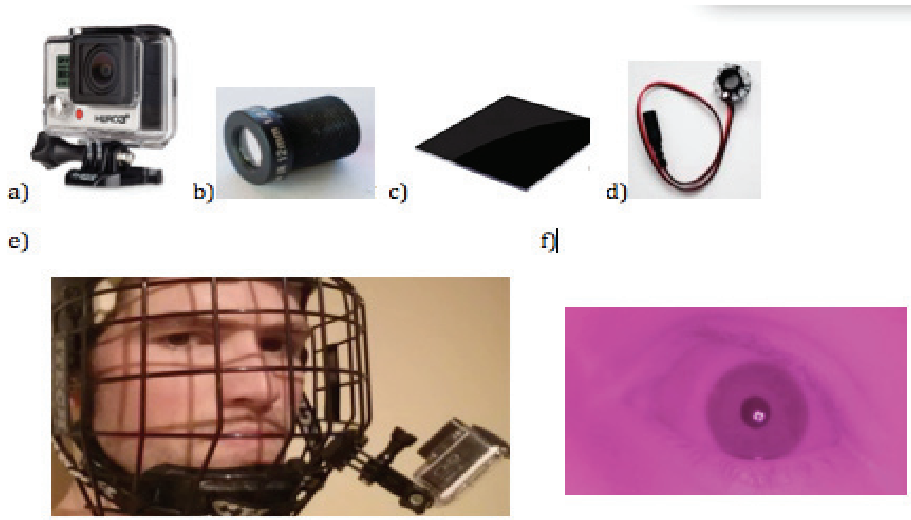


Figure 2. a) GoPro Hero 3+ Black Edition camera. b) 12 mm wide-angle lens. c) Optical cast Infrared long pass filter. d) Infrared LED illuminator. e) Camera attached to cage of helmet. f) Sample image of the eye as seen by the infrared camera. A technical description of the eye-tracking system can be found in Appendix D

An integrated accelerometer and gyrometer from Icewire technologies (AG1: http://www.icewire.ca) (Figure 3) was fastened to the top of the players' helmets. The data from this device were used offline to obtain 3D head angle in relation to the gravitational vector (head-in-world angle). Offline, eye-in-head angle and head-in-world angle data were combined to derive vertical gaze angle (eye-in-world).

*Figure 3***.** Icewire AG1 data logger with integrated accelerometer and gyrometer.

Intervention Tools

Quickstickz is compatible with Microsoft windows XP, Windows Vista, or Windows 7, with a minimum intel Pentium 4 processor, 512 MB of RAM, Microsoft Internet Explorer 6 or Firefox 2, and internet access. It is connectible through a USB port. Quickstickz comes with a ball equivalent to the weight of an official game puck, at 6 ounces. The shape of the ball allows for movement off the ice similar to the movement of a puck on ice. Participants were instructed to use a harder surface at home as opposed to carpet, which would allow for smooth motion while controlling the ball. Participants were also required to play in an area that would allow sufficient space to perform all of the drills (Figure 4).

The ball is equipped with video sensors that are tracked with the Quickstickz camera, and ball motion is displayed on screen as a virtual representation. Quickstickz software offers many drills and games, but for the purpose of this study, three different circuits (sets of drills) were selected. These three circuits comprised the appropriate amount of time required for a training session with some free time for the participants to try any drills they would like at the end. The circuits represent a broad range of puck-handling skills, which allowed for realistic skill variation. The chosen circuits and drills are described in detail in the procedure section, as well as in Appendix E and all Quickstickz information can be found at (Quickstickz.com).

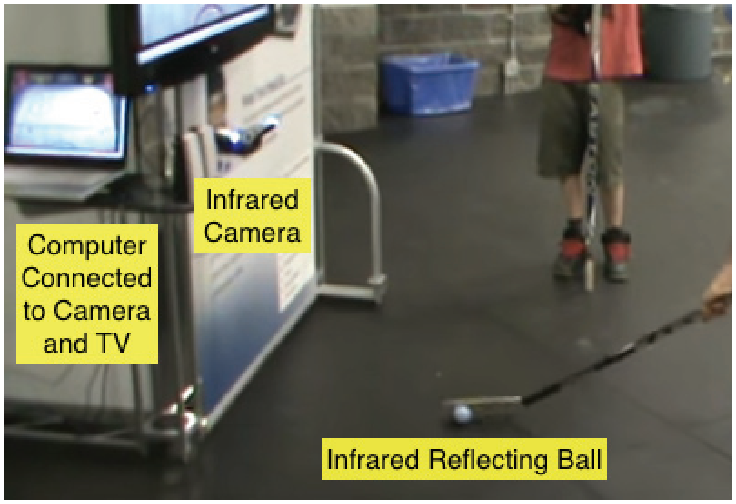


Figure 4. Quickstickz home based training, and recommended area of gameplay.

Procedure

The study protocol consisted of 10 weeks, with three on-ice testing sessions and two training intervention periods, as shown in Figure 5.

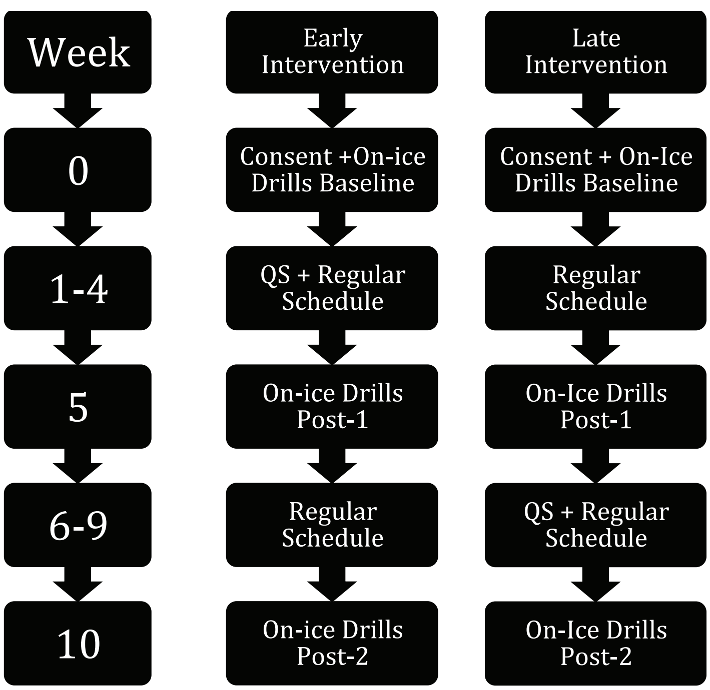


Figure 5. Study protocol for on-ice testing and Quickstickz training (QS=QuickStickz intervention).

On-Ice Baseline

Participants were assigned to groups prior to testing, and were notified of their group when they arrived at the arena for the on-ice baseline test. This was done through random number generation in Microsoft Excel. Participant assent and parental consent were obtained (Appendix, and both were asked to fill out a consent form.

During the baseline test, each participant was fitted with the Go-Pro camera for eye-tracking, and the integrated accelerometer/gyrometer to track head angle. The other participants were warming up in the opposite end with a coach. The camera was linked to a phone application in order to make sure it was fitted in the correct spot, and that the pupil was clearly visible. The infrared light battery was affixed to the back of the helmet. The accelerometer/gyrometer was affixed to the top of the helmet, with the X-axis pointing forward, the Y-axis pointing left, and the Z-axis pointing upward.

Calibration of the eye-tracking camera was required so that pupil co-ordinates in the camera's image could later be converted into horizontal and vertical eye-in-head angles. Each participant stood 55 cm away from the calibration board which contained nine dots separated by known distances, thereby creating a matrix of nine different eye angles in the horizontal and vertical axes (Figure 6). The board was altered so that the center dot was level with the particular participant's straight-ahead gaze angle. The camera recording was started and then participant fixated each dot on the calibration board, beginning with the center dot, moving left one dot, then up one dot, clockwise until all dots were fixated for one second each. The accelerometer/gyrometer was calibrated for the gravitational vector by letting it lay on a flat surface for 10 seconds, before fixing it to the top of the helmet.

The participant was then led to the first set of obstacles on the ice, where they would perform the first drill. They were instructed to keep their gaze up as best as possible, while performing the drill as quickly as possible. Time to complete each drill was monitored using a stopwatch (Casio timer). The timer was initiated at the participants' first stride, and stopped when the participant crossed back over the initial start point. Time to complete the drill was written down in a notebook.

Drill 1, Forehand/Backhand passing, consists of players skating a route around pylons, making backhand or forehand passes. Drill 2, the Weave Agility Skate, has cones spaced 10 feet apart. The player skates up past all cones, performs a tight turn around one cone and weaves through the cones, tight turns back through cones, with a final tight turn and skates hard to the red line. Drill 3, Figure 8 Stickhandling, has cones set 4 feet apart, and players having to stickhandle in a figure 8 motion, switching direction after 5 cycles. Drill 4, the Transition Agility Skate, has cones at 24 feet apart. The player skates forward, pivots backward down along outside, pivots forward again to skate down along the opposite side, skates forward to a stop at the top of the circle, and backwards all the way back to the beginning while controlling the puck. All drill time data were transferred to a Microsoft Excel spreadsheet for off-line reduction, cleaning, and analysis.

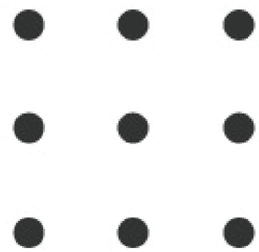


Figure 6. Calibration grid for off-line conversion of pupil images into eye angular position. Calibration dots were separated from each other by 30 cm in the horizontal and vertical axes. Participants viewed the grid from 55 cm away with the central dot aligned with their straight-ahead gaze.

Early Intervention Phase

During this phase, participants in both groups attended their regular team practice and game schedule. Participants in the early-intervention group each received a Quickstickz game package and were instructed to take the game home after the pre-intervention on-ice test, and were given login data and installation instructions. The login data were used to track playing time online, in total number of minutes played. Participants were reminded of the training schedule which required them to play Quickstickz no more or less than the required 30 minutes per day, 4 days a week for four weeks, for a total of 480 training minutes.

Participants were asked to complete circuits 1, 2 and 3 in order, for a total of 24 minutes, and had 6 minutes to perform their drills of choice. Circuit 1 is a combination of Soft Touch for one minute, Obstacles for 2 minutes, and Targets for 2 minutes. Circuit 2 is a combination of Soft Touch Around The Body for 1 minute, Obstacles for 2 Minutes, Narrow Dribble for 2 minutes, Wide Dribble for 2 minutes, Figure 8 for 2 minutes, and Targets for 2 minutes. Circuit 3 is a combination of Forehand Fake for 2 minutes, Narrow

Dribble/Soft Touch for 2 minutes, Figure 8 for 2 minutes and Backhand Fake for 2 minutes. More detailed descriptions of these drills can be found in Appendix C. Training time was tracked online.

The area of play around where Quickstickz is set at home was instructed to be a combined stick and arm length distance radius around each individual participant, to ensure they would have enough room to complete the motions necessary for each drill (Figure 4).

On-Ice Drills Post-1

The on-ice drills and data collection procedures at this phase matched exactly those of the baseline assessment phase. The early intervention group returned the Quickstickz game packages, and the late intervention group received them to take home for the subsequent phase.

Late Intervention Phase

During this phase, participants in both groups attended their regular team practice and game schedule. The participants in the late intervention group completed the necessary Quickstickz training intervention as outlined earlier for the early intervention phase.

On-Ice Drills Post-2

A final on-ice assessment was completed at the close of the late intervention phase. All Quickstickz units were collected at this time and returned to the Quickstickz company. Participants were debriefed and thanked for their time and participation.

Data Reduction and Analysis

Summing Individual Drills into a Composite Drill Time

There were four on-ice testing drills completed at each assessment phase, as described earlier. The drills were originally timed and recorded separately due to superficial differences in the underlying skills tested. However, an analysis was conducted to determine if it was appropriate to combine all four drills into a single composite measure in order to reduce the number of statistical comparisons. A multivariate analysis of variance (MANOVA) was conducted including the four separate completion times for the drills as dependent measures in a 2 x 3 design with independent factors of group (early vs. late intervention) and time (baseline, post-test1 and post-test2). The analysis did not reveal any significant interactions involving Drill number (all $p > 0.05$), suggesting that all dependent measures responded similarly to the independent variables and could therefore be combined into a single composite measure without losing useful variation.

Combining Groups

As described earlier, a change was made to the analysis plan due to the large number of drop-outs. Rather than comparing the two groups on all outcome measures at the post-1 phase, a decision was made to combine the two groups to create single pre-intervention and post-intervention set of outcome measures. Before combining the groups, it was important to determine if the groups differed significantly from each other for their respective pre-intervention assessment phases since these values came from different points in time. Independent samples t-tests were used to compare the baseline values for the early intervention group with the post1 phase values for the late intervention group, as these represented the corresponding pre-intervention time points. These tests revealed no significant group differences for drill completion time, $t(8) = 0.7$, $p = 0.7$, average vertical gaze angle, $t(8) = -0.6$, $p = 0.2$, and gaze-up percentage, $t(8)= -0.2$, $p = 0.7$ (Table 2). Consequently, the groups were combined into a single pre-post comparison design. The collapsing of groups eliminates the control group, which will affect the validity of the data in its ability to control for external variables such as improvement made through regular practices and games. However, strength for predicting future sample sizes was the priority in the analysis.

Table 2.
Results of independent samples t-test between groups for pre-intervention values for all outcome measures. 'n' being the number of participants included in this analysis, 't' is the test statistic, 'df' the degrees of freedom, and p, probability that the difference can be explained by chance, being significant when less than 0.05. Values are mean ± sd.

Measure	Group (n)	Pre-Intervention	t	df	p
Drill Time	Early (6)	121s±9s	0.7	8	0.7
	Late (4)	116s±12s			
Avg Gaze Angle	Early (6)	$-16^{o}\pm47^{o}$	-0.6	8	0.2
	Late (4)	$0^{o}\pm25^{o}$			
% Gaze-Up	Early (6)	40%±33%	-0.2	8	0.7
	Late (4)	44%±37%			

Drill Time

As described earlier, individual drill times from each on-ice test were combined into one total drill time, so that each participant had one pre-intervention time and one post-intervention time.

Average Gaze Angle

The gaze angle data for each drill was combined into a total gaze angle stream from each particular on-ice testing session, so that each participant had a pre-intervention set of gaze data and a post-intervention set of gaze data. An average of each participants' gaze data was calculated from the complete stream of data from each on-ice session.

Percent Gaze-up

The continuous vertical gaze angle data for each drill were evaluated at each time point as being above (>0 degrees) or below (<0 degrees) the calibrated horizontal axis, and converted to a percentage of total drill time with gaze above the horizontal ('gaze-up time') by dividing by the total number of time points for each drill.

Gaze Behaviour

Eye-in-head angle (horizontal and vertical) was calculated from pupil location data gleaned from the video footage recorded during on-ice drills, and combined with head-in-world angle derived from the integrated accelerometer/gyroscope data collected from the helmet (See Appendix B for technical details).

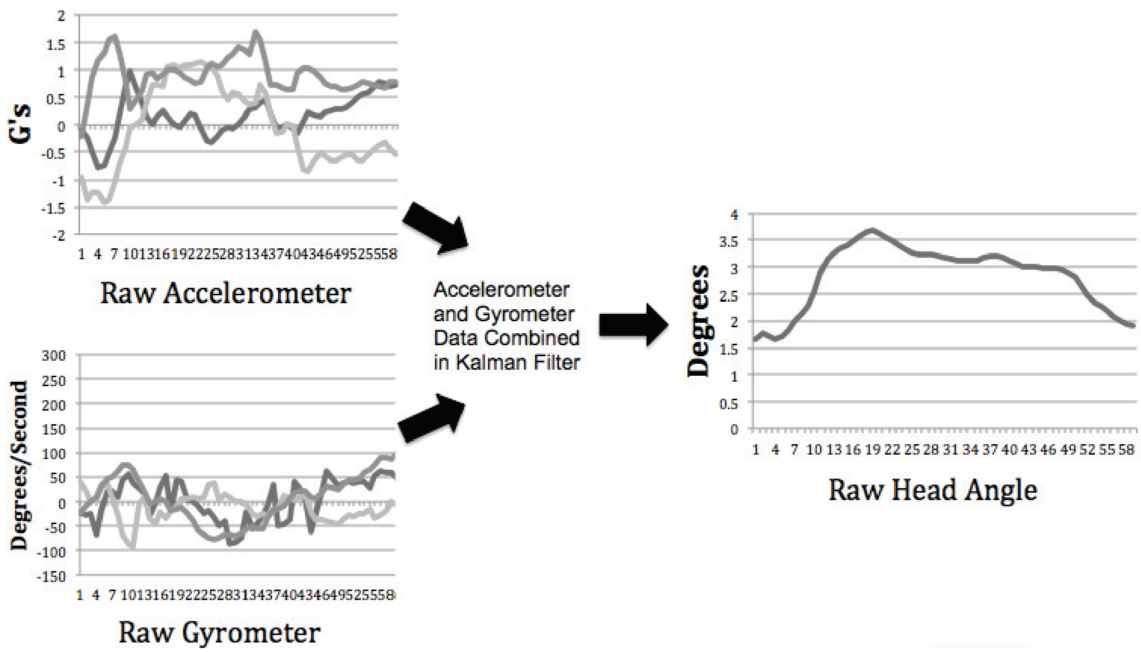


Figure 7. AG1 data extraction process, using calibration and one on-ice drill reading as an example. The 3 shaded lines represent each of the x-y-z axis. The Raw Accelerometer and Gyrometer readings are entered into the Kalman Filter, which accounts for drift and combines the data over time, forming head angles in a single data tracing of vertical pitch

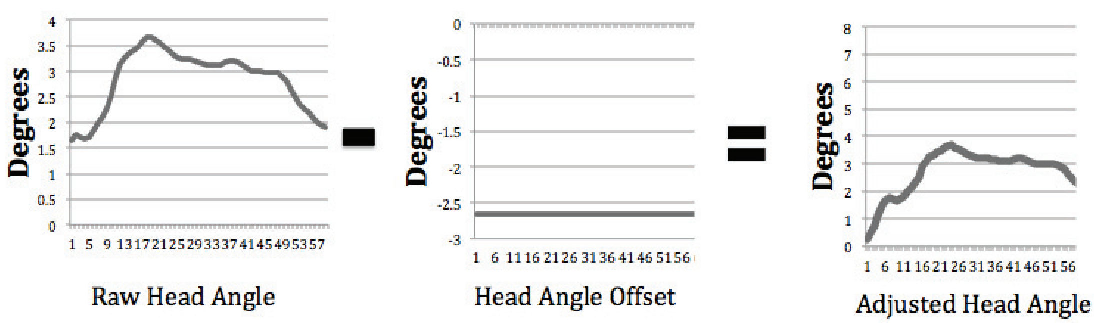


Figure 8. The head angle offset subtracted from the raw head angle data result in a vertical head angles for each drill.

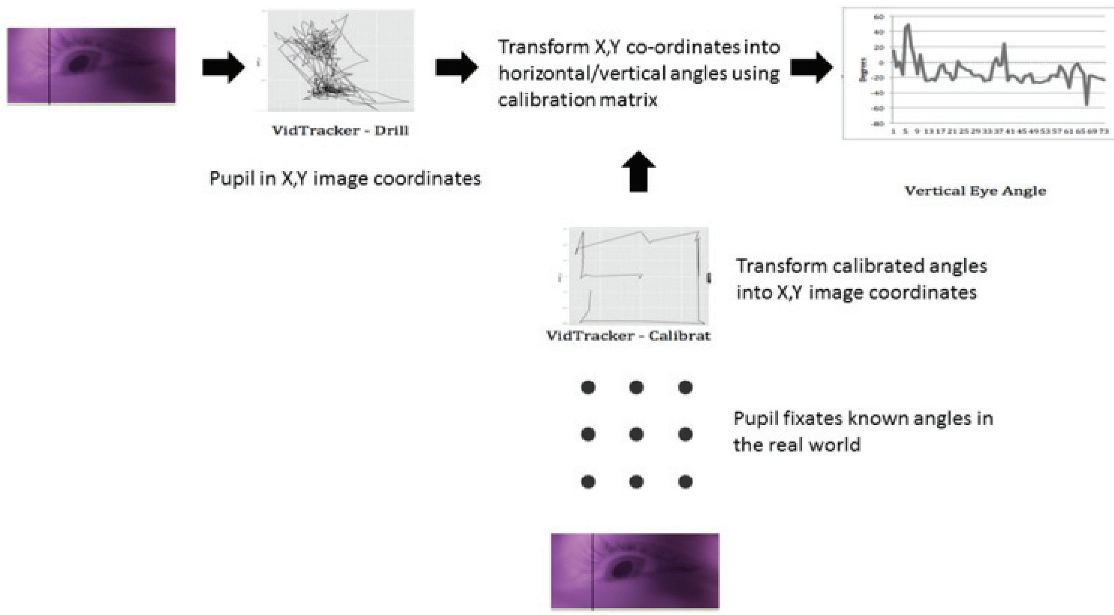


Figure 9. Gaze angle extracted from the video using data from the same on-ice drill. The camera is calibrated using the process described earlier and grid from Figure 6. The video is analyzed using vidTracker to produce y-coordinates based on the pupil locations and the corresponding pixilation. The calibration is combined with the gaze coordinates in the software 'R', to produce a vertical eye angle reading for the drill.

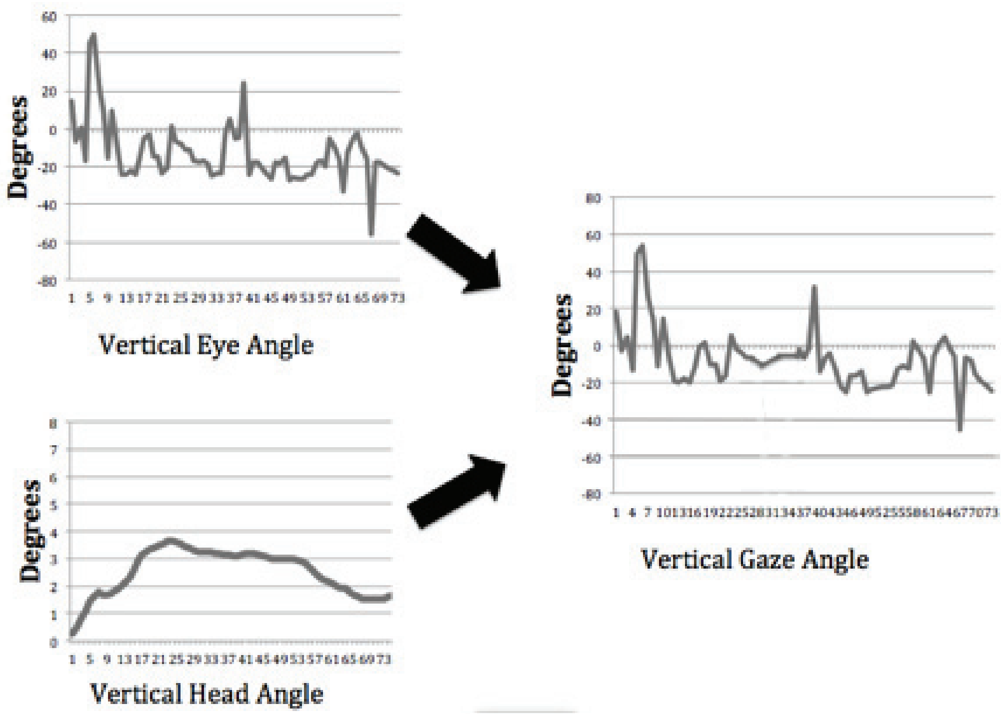


Figure 10. Combing outputs of AG1 (vertical head angle) and video data (vertical eye angle) over time throughout one drill (x-axis), to produce the final sum, the gaze angle.

Data Cleaning

Only the 10 participants with complete data sets for pre-intervention and post-intervention were included for data analysis. The main reason cited for withdrawal between the first and second post-test was that data collection commenced too late into the hockey season. Verbal reasons were given concerning these dropouts, all of which stated that with the transition into the summer months, different sports and activities were creating busier schedules, and they were no longer able to take part in the trials. The numbers of participants included in each statistical analysis are outlined and justified in the results section.

Statistical Analysis

Pre-intervention means for the early- and late-intervention groups were analyzed using independent samples t-tests to determine if baselines between the two groups were similar prior to collapsing into a single group. Pre- and post-intervention means were compared using a paired-samples t-test with an alpha of 0.05. Power analysis was conducted using G*Power 3.1, based on the effect size (sigma) and error variance (sampling error of the mean) for average vertical gaze angle, and percentage of gaze-up time, to estimate the sample size necessary to achieve 80% power for future research (12).

CHAPTER 4: RESULTS

Compliance with Protocol

The number of minutes spent playing Quickstickz over each month of the intervention was tracked online. The participants were asked to spend 30 minutes a day, 4 days a week, for 4 weeks on training with Quickstickz. Out of the 30 minutes, 24 minutes were prescribed drills that were required to be completed, with the other 6 minutes being participant choice to increase enjoyment and compliance as outlined in methods. Perfect compliance equates to a total of 480 training minutes. For the ten participants included in the main outcome analysis, the average training completed was 430±46 minutes. It was not possible to check if they complied with daily and weekly schedule, as only total number of training minutes were reported on the tracking system.

Main Hypothesis Testing

Results of the main hypothesis are described in Table 3, and represented in Figures 11-16 below.

Table 3. *Results and descriptive statistics for paired samples t-test between pre- and post-intervention values for each dependent measure (mean*±sd).

Measure	Pre	Post	t	df	p
Drill Time	119s±10s	110s±11s	2.6	9	0.03*
Mean Gaze Angle	-10°±38°	1°±21°	-0.8	9	0.45
% Gaze-Up	40%±29%	50%±25%	-1.2	9	0.27

Combined Drill Time

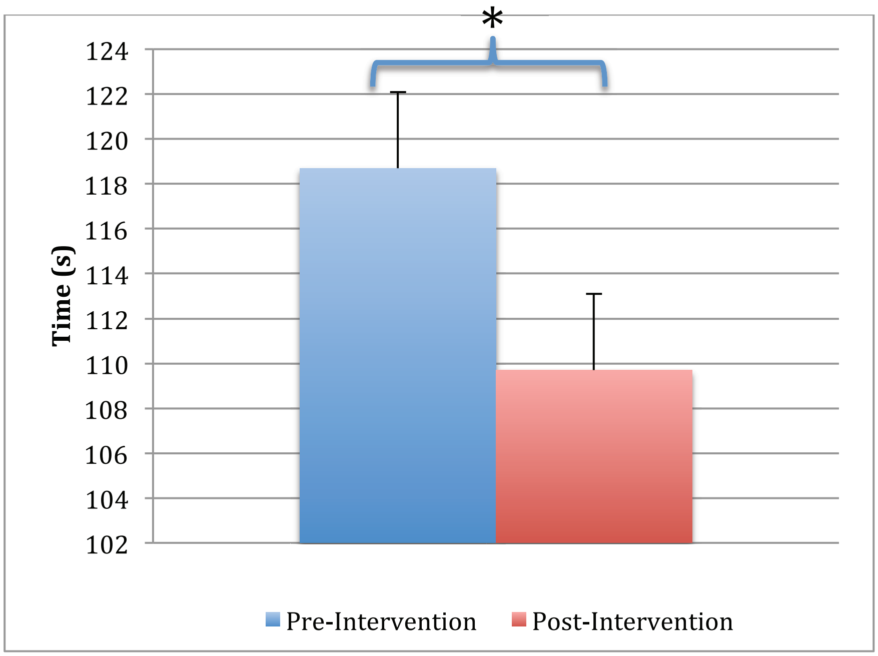


Figure 11. Average time to completion of drills from pre-intervention to post-intervention. Significant difference denoted by '*'.

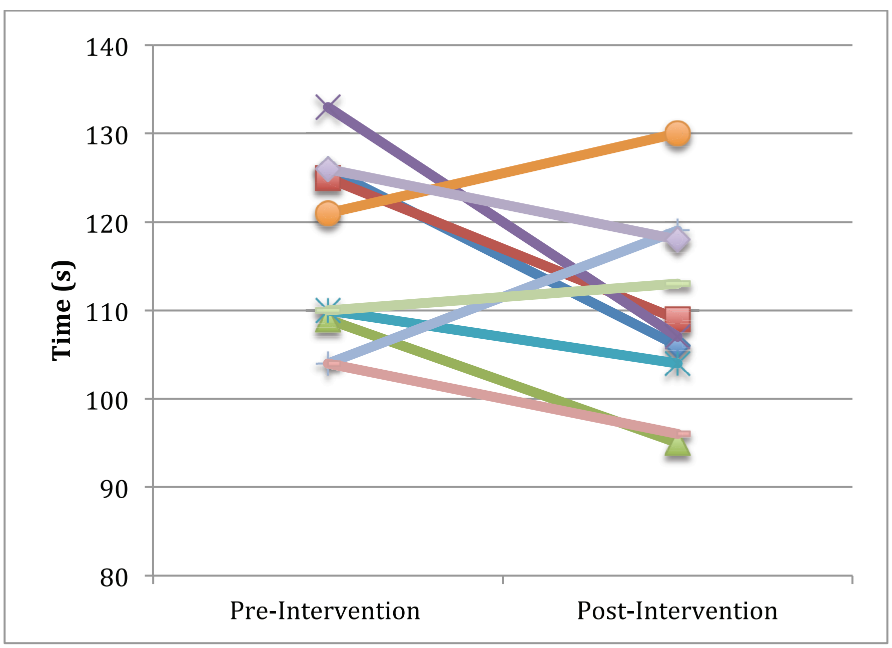


Figure 12. Total time to completion of drills per participant, pre-intervention and post-intervention.

Average Gaze Angle During Drills

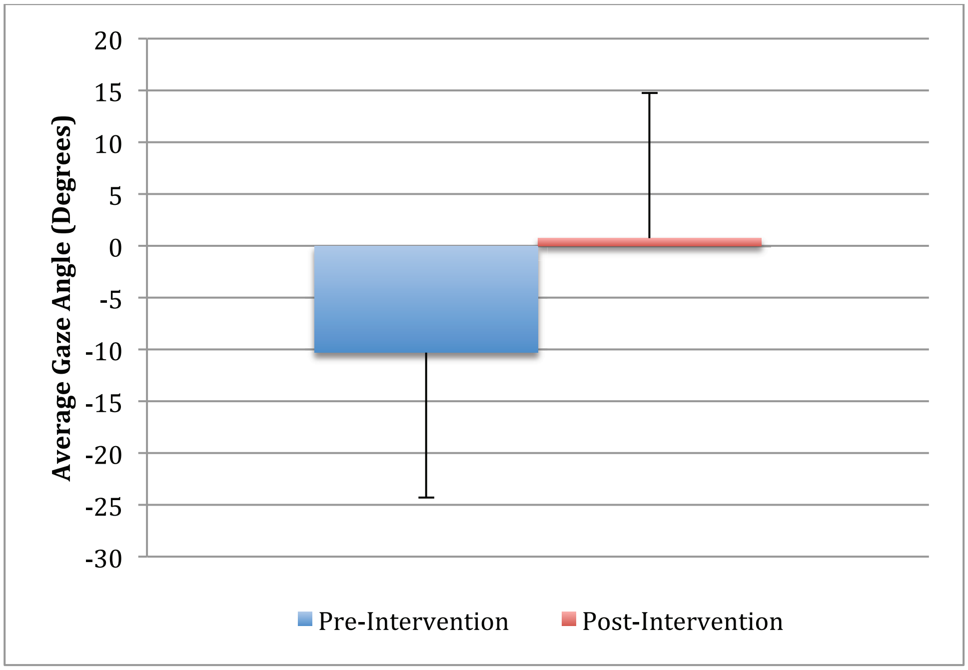


Figure 13. Average gaze angle from pre-intervention to post-intervention.

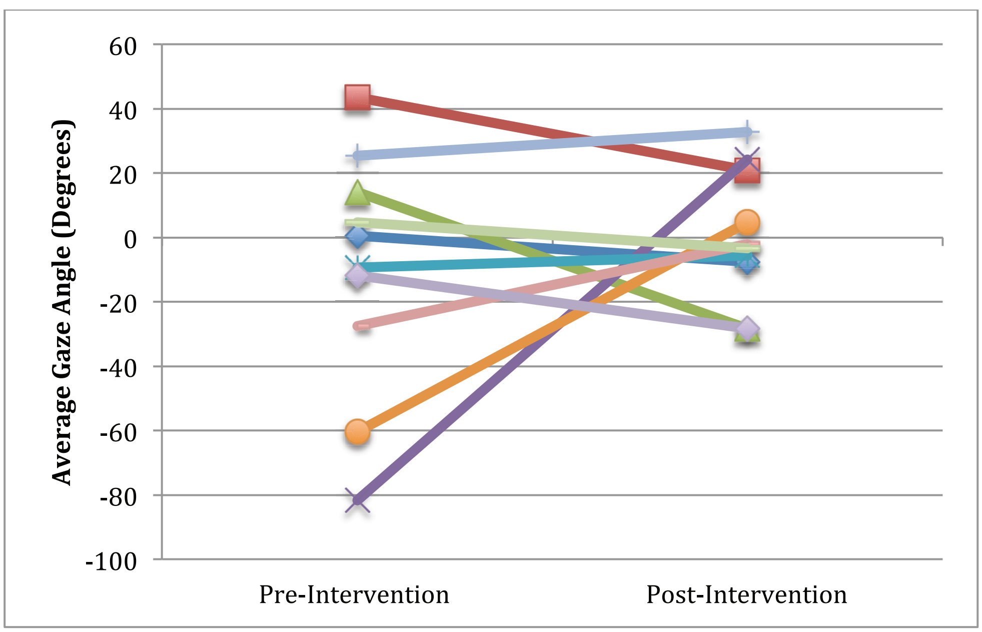


Figure 14. Gaze angle of each participant from pre-intervention to post-intervention.

Percent of Drill Time with Gaze-up

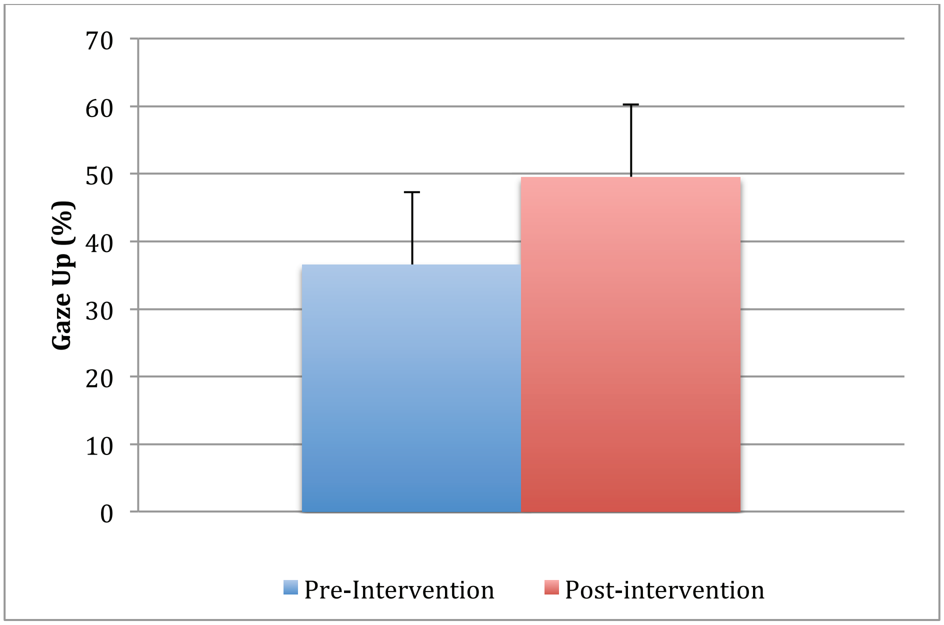


Figure 15. Percent Gaze-up time (above horizontal) from pre-intervention to post-intervention. Difference between pre-intervention and post-intervention is not significant.

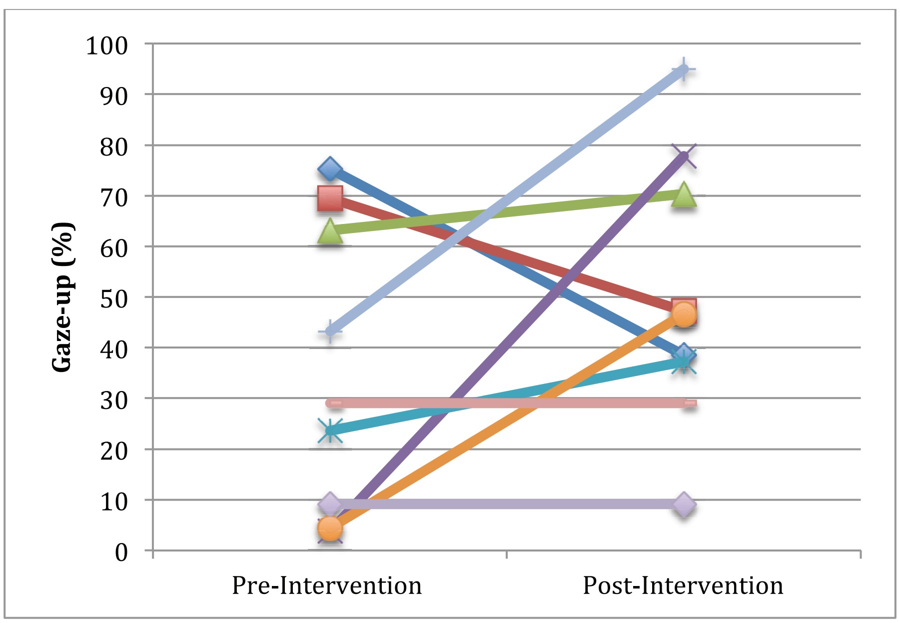


Figure 16. Percent Gaze-up time for each participant, from pre-intervention to post-intervention.

Speed/Gaze-angle Trade-Off

In measuring gaze during speeded drills, there is a concern that participants may sacrifice speed in order to achieve the goal of maintaining upward gaze (or vice versa). In order to determine if participants were trading off gaze-up time with performance on the drills, correlations were calculated between percent gaze-up time and drill time for both pre-test and post-test. If participants were trading off drill speed for maintain upward gaze, then a significant positive correlation would be expected between gaze-up percentage and drill completion time (i.e., slower drill performance reflected by longer completion time would be associated with a higher percentage of time spent with the gaze up), and also between average gaze angle and drill time. The correlation at each time point is represented in Table 4, below. In short, there was no evidence to support such a trade-off.

Table 4.
Pearson Correlation between gaze-up and drill time, at each time point (1=baseline, 2=post-1, 3=post-2). 'N' indicates number of participants that performed the drill at this time point. 'N' drops from 17 to 10 as 7 participants dropped out of the study before the final on-ice test. P indicates a significant correlation if less than 0.05, denoted with a ''*

Variable (On-Ice Test #)		Drill Time (1)	Drill Time (2)	Drill Time (3)
Gaze-Up (1)	Pearson Correlation	-.12		
	P	.64		
	N	17		
Gaze-Up (2)	Pearson Correlation		-.44	
	P		.08	
	N		17	
Gaze-Up (3)	Pearson Correlation			-.18
	P			.62
	N			10

Critical Sample Size Estimation

Based on the effect size estimates for the two outcome measures that were not statistically significant (i.e., mean gaze-up angle and gaze-up %) , a statistical power analysis returned estimated sample sizes of 48 and 21 respectively for a single group, pre-post within-participants comparison.

CHAPTER 5: DISCUSSION

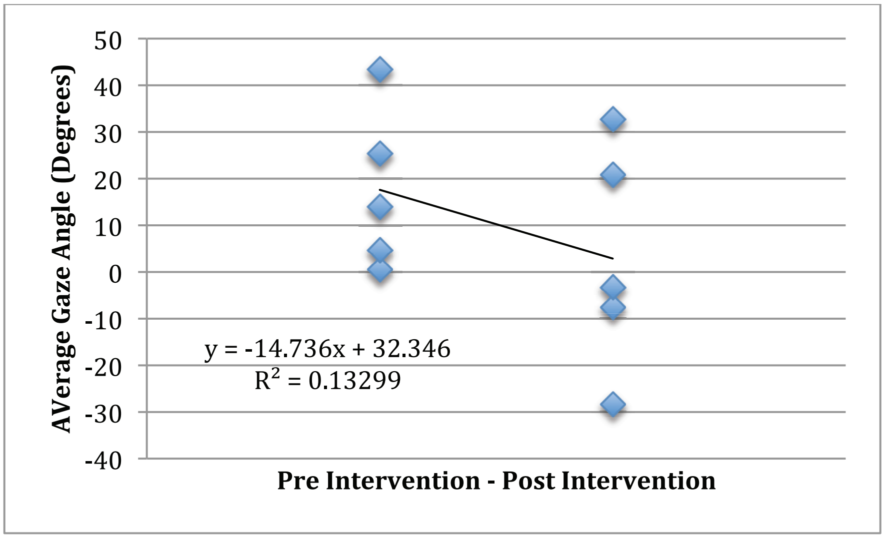
The Quickstickz game is designed to promote puck control skills in hockey players, and to encourage upwards gaze when doing so. It was hypothesized that a 4 week intervention with the game would transfer these skills to on-ice hockey drills, leading to a reduction in the time to complete those drills. More importantly, it was predicted that Quickstickz training would lead to an increase in the percentage of time spent with the gaze in an upward direction during on-ice drills. Relatedly, it was hypothesized that the average gaze angle throughout the on-ice drills would be more upwards than prior to the intervention.

The results of this exploratory study provide mixed support for the research hypotheses. On the one hand, participants were faster at completing on-ice hockey drills after a month of training with Quickstickz compared to where they were at the beginning the intervention. Importantly, correlation analyses between gaze measures and drill completion time did not support a simple trade-off between gaze behaviour and performance on the drills. In other words, reductions in drill completion time were not gained at the expense of spending more time looking down at the puck rather than up at the surrounding environment. The results also do not demonstrate a significant improvement in gaze-up behaviour after the intervention in terms of the average vertical gaze angle during on-ice drills, or the percentage of drill time spent with a vertical gaze angle. Nevertheless, the trends showed a pattern consistent with improved upward gaze behaviour after the Quickstickz intervention, and statistical power analyses indicated that a study with 20-48 participants would likely achieve statistically significant results for these gaze measures.

Another important observation following visual inspection of individual participant data (Figures 12 and 14) suggested a pattern of response to the intervention that might be related to the individual's initial vertical gaze behaviour. Of the 5 participants with downward horizontal initial average gaze angles, 4 of them demonstrated a greater degree of improvement after the intervention (from 20 to 100 degrees). Also, of the 6 participants that performed below 45% gaze-up time at their initial on-ice test, 4 of them demonstrated a greater degree of improvement (from 8% to 70%). Conversely, some of the participants with higher gaze-up percentages (3 out of 4 above 45%) and average vertical gaze values (4 out of 5 above horizontal) showed little or no improvement after training.

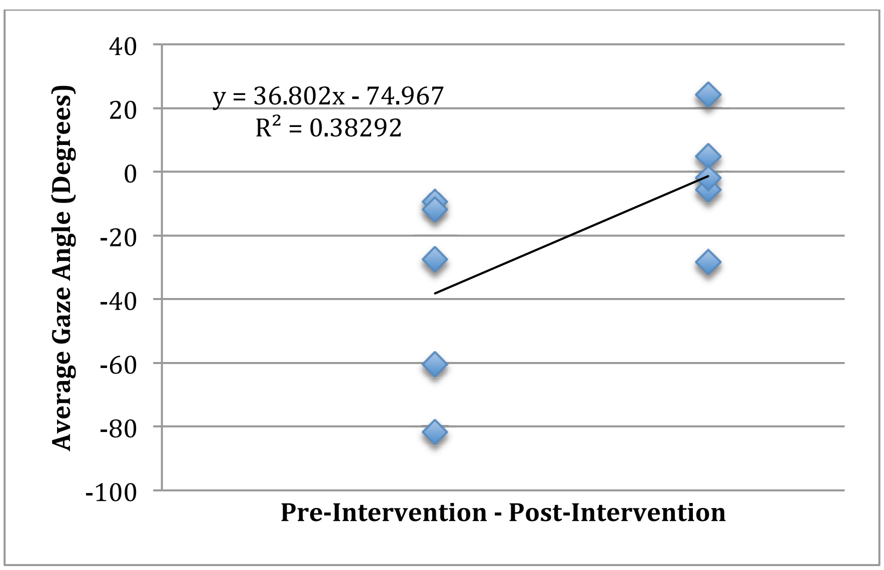
Changes in gaze behaviour: a link to stages of learning?

The study looked for evidence that the video game training tool Quickstickz could effectively teach hockey players to improve their upward gaze behaviour during puck handling on the ice. Although no significant gains in upwards gaze behaviour were found, the direction of the pattern was consistent with the hypothesized effect. Furthermore, an inspection of individual participant results suggests that greater improvements occurred for players with poorer initial vertical gaze metrics as described earlier, as represented by the correlations in Figure 17. It is possible that Quickstickz training provided benefits to novice or weaker players, as opposed to those were already performing like experts. The participants in future studies could be divided into these phases based on their abilities prior to the Quickstickz intervention: those that scored lower on the baseline testing, and those with very high scores to begin with, and perhaps provide more challenging drills to the more expert performers.



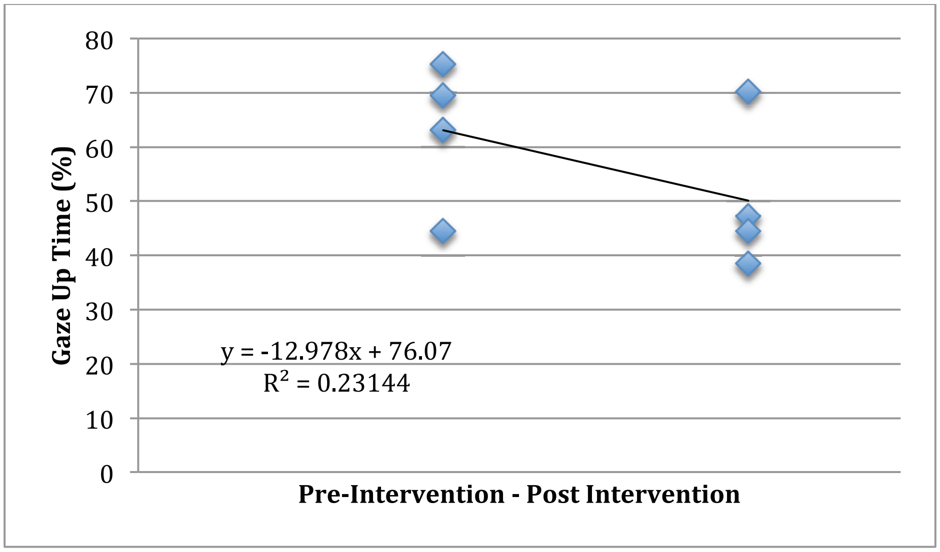
50
40
30
20
10
0
-10
-20
-30
-40
AVerage Gaze Angle (Degrees)
y = -14.736x + 32.346
R2 = 0.13299
Pre Intervention - Post Intervention

A)

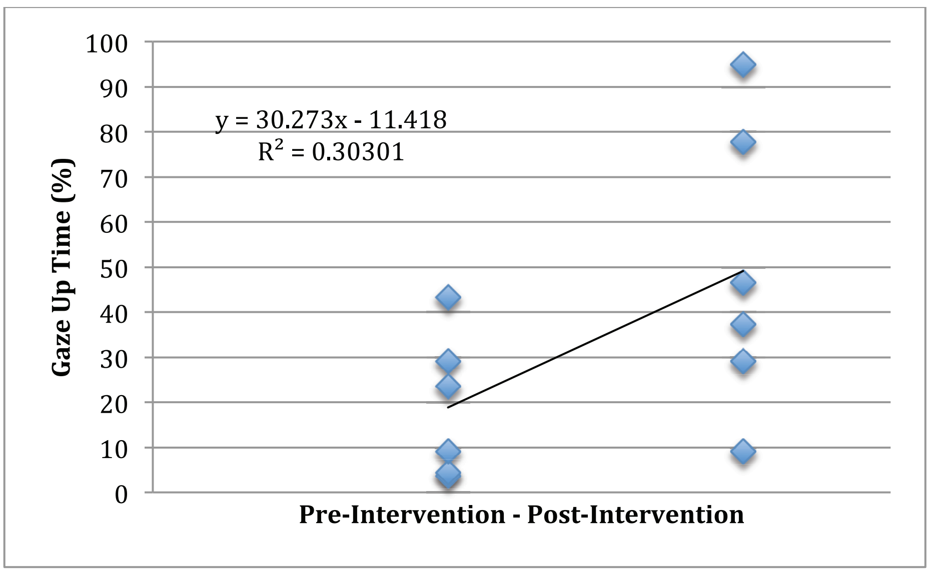


40
20
0
-20
-40
-60
-80
-100
Average Gaze Angle (Degrees)
y = 36.802x - 74.967
R2 = 0.38292
Pre-Intervention - Post-Intervention

B)



C)



D)

Figure 17. Correlations between Pre-Intervention and Post-Intervention individual data based on initial performance. A) Gaze Angle Correlation (Above 0° Initial Performance); B) Gaze Angle Correlation (Below 0° Initial Performance); C) Gaze-Up % Correlation (Above 45% Initial Performance); D) Gaze-Up % Correlation (Below 45% Initial Performance)

Improved on-ice drill performance: Quickstickz, or familiarity?

The reduction in on-ice drill completion time was significantly reduced in participants following the Quickstickz training intervention, however it cannot be concluded with confidence that the intervention was responsible for the improvements due to the lack of a control group in the modified statistical analysis of the results. Because the early and late intervention groups were collapsed and simply compared from pre-intervention to post-intervention, any number of factors could have changed over that time period to improve hockey-related skills. For instance, participants would have been relatively unfamiliar with some of the on-ice drills at the earlier testing session, and the increased familiarity at the subsequent testing session alone could have led to improved performance. Similarly, because participants were engaged in regular hockey practices and competitions alongside the intervention, the post-test performances would have been influenced by general improvements in hockey-related skills obtained during the course of the playing season. Obviously, such confounds were anticipated in the original experimental design which would have permitted an adequately controlled between-groups comparison of the intervention to a no-intervention group at the first post-test phase, but such an analysis would have been grossly underpowered given the number of participants that withdrew from the study at various time points.

Transfer: Performance in Training and Gameplay

Quickstickz provides heads-up feedback of a task that normally would not be visible during real hockey. The display of the puck on the screen allows the player to know where the puck is moving in real-time, whereas in actual hockey, the head-up would provide a player with vision of an opponent or the environment. This creates a dual-task scenario, forcing reliance on other sensations for the puck control task. Even the slightest of errors while performing the stickhandling movements with the head-up may result in a displacement of the puck that is not in line with the predicted sensory feedback (24). If this error is large enough, the participant would have to look down for a visual confirmation of where the puck is, in order to regain control. Limiting these types of errors will increase the average angle and the percentage of gaze-up time, which is the goal of the training intervention. During Quickstickz training, the on-screen movement of the ball gives the participant an idea of where the ball is during these mistakes, so that they can avoid looking down. On the ice, however, the participant must either rely on proprioceptive feedback or revert to visual feedback when a mistake occurs. The priorities are to avoid mistakes altogether and maintain control the entire time, and train the proprioceptive feedback mechanisms to keep track of the ball and puck while stickhandling in order to correct when mistakes do occur, so that attention can be allocated to environmental awareness, quick reactions and decision making. The main premise of the study is that hockey requires multitasking, and injury avoidance in particular requires visual scanning while doing other tasks without direct attention or visual input.

This point of differing goals in training versus gameplay leads into the discussion of transfer. An example of transfer issues in other research included a study that investigated the use of video games in training sports skills. Johnson et al. (17) investigated the ability of Xbox Kinect to improve fundamental movement skills in children 6-10 years of age, in order to improve their confidence so they would want to continue being physically active. The games they played during the intervention were all sports, such as golfing and racquet sports. The intervention lasted 6 weeks, with participants playing a variation of the sports games on the Xbox Kinect once a week for 50 minutes (17). No significance was found for improvements in fundamental motor skills on tests of one and two hand striking, ball bouncing, kicking, and throwing (17). Training involving these general movements in the sports may not have any bearing on how well a participant performs a skilled, goal-oriented movement, as suggested in the results of the study. Transferring the ability to avoid contact by training gaze-up and puck control ability with Quickstickz may be more effective if the drills included an element of avoiding other players, rather than simply moving the puck to different targets and making or avoiding contact with these targets (16). Future studies could possibly include a slightly adapted Quickstickz training game.

Practical Implications

A Quickstickz training intervention should have the appropriate target participants, regardless of the level of play or age. The fact remains that concussions and injuries occur at all levels of hockey (12,25). Even if a player is playing professional hockey, they may not be an expert at controlling the puck while maintaining an upward gaze. Any player that controls the puck with their head down may be susceptible to injury as well as suffering from hindered performance. Quickstickz would do well do quantify and attract these players, as they would have the potential to experience the most improvement. Quickstickz also uses a design that overlays what is happening on the ground up on to the screen. This is essentially different from an actual game scenario, where the purpose of maintaining the gaze-up is to observe the environment, opponents and teammates in order to act and react to the game situations. If Quickstickz is able to replicate in-game scenarios by using a first-person style game, for example, transfer of learning may be even stronger with the increase in practice specificity. Although Quickstickz may provide benefit as is, it would be interesting to see design and adaptations, which may improve the ability to transfer to game situations and help target a wider population of players.

Although Quickstickz does have room for improvement as far as a training intervention game, it does provide a new, cost-efficient way to continue developing hockey skill outside the rink in a way that clearly appeals to children. Not only can training with Quickstickz at home reduce costs for parents, it may help young players avoid psychological burnout by providing them with a fun way to develop their skills away from the rink and the pressures of coaches, teammates, and parents. It is important for young players to learn in a dynamic, enjoyable environment that allows them to develop creativity and passion for the game (13).

Limitations

The major limitations of the study are related to the premise of preventing concussions in hockey. In order to test a concussion prevention method directly, the number of concussions sustained before and after training must be known. Measuring concussion rates is difficult, as there are differing degrees of concussions after head trauma, and many concussions go unreported (41). The research hypothesis, that Quickstickz will improve participant's ability to keep their head-up during play, is made under the assumption that if a player is able to play with their gaze-up, they will be able to avoid concussions. These limitations are difficult to avoid in a study involving injury prevention, as it is not ethically acceptable to willfully subject participants to concussion causing circumstances. Therefore, the study was set up under the following assumptions:

that players who kept their head-up while controlling the puck during play are able to see their opponents; that seeing the opponent assists the player in avoiding contact; and that players who are able to avoid contact can avoid concussions.

Design

Unintentional limitations included low compliance. Of the two reasons provided for low compliance, one was that data collection commenced too late into the hockey season. Hockey season at this age typically begins in September and runs into April. Some players elect to play spring hockey into May, but other than summer hockey camps, most players are typically off the ice for the months of May-August. As it was a 2-month long study commencing in April, the final on-ice test did not take place until June. At this point, many participants were into summer sports and reported being too busy with other things to continue the study. A future study should take place earlier in the hockey season, as the excitement and interest in the game is at its peak.

Another reason for drop out, reported verbally and through email correspondence, was frustration with the Quickstickz gameplay. The Quickstickz game uses reflective infrared technology to track movements of the ball for on-screen real-time movements. Therefore, the game works best in an environment where there is little to no infrared light from other sources. Incandescent bulbs emit infrared light, and those participants that were playing the game in a room illuminated using these types of bulbs would experience a jittery puck that would not respond correctly on the screen. This was reported as frustrating for some participants. Compliance with training minutes was not perfect either. Participants were to perform the Quickstickz training drills 4 days a week, for the full 30 minutes per day. Some participants fell short of this as they missed a few training sessions (430±46 minutes, range: 379 to 480). In future studies, a lab with the correct environment could host participants to come in and practice under a supervisor that could help with any issues, ensuring compliance. The age group was chosen because it is the last age group before contact begins in hockey, and would be the optimal age in which developing the ability to keep the gaze-up while stickhandling would help prevent injury. It is good to have results based on this specific population, but as Quickstickz is a game for all ages, it would also be beneficial to include a wider range of ages in future studies for generalizability to the entire population of players.

Equipment

With more convenient and practical eye-trackers coming onto the market, something small enough that could fit inside of a helmet and facemask without obstructing view may help the future of this type of sports research. That being said, this study assesses the outcome measure gaze-up percentage, which is based on the percentage of time the participant had their gaze at some angle at or above horizontal (as calibrated prior to testing, depending on participant height and posture). The choice of gaze measures were defined based on this arbitrary definition of 'up'. If a participants' gaze was just below horizontal by this definition, they could potentially still be able to scan the environment. A better definition of upward gaze in hockey would allow for a stronger assessment of the fidelity of training. An ideal way to quantify this data in this study, given the current equipment, may be to take test trials in which the participants is controlling the puck with their head down looking at the puck the entire time, and a separate trial with their head up visually scanning the environment. This data could then be correlated with the assessment data to provide a more accurate measure of what each individual participant is actually looking at while controlling the puck during drills.

Future Directions

Links to Contact Avoidance

Whether or not the results of the study or future studies employing the same study design actually helps to reduce concussions and other injuries through contact avoidance is yet to be seen. One of the major assumptions of this study is that players that play with their head up rather than down when they have the puck get hit less, and that those players that get hit less sustain fewer concussions and other injuries. With a camera capable of being worn in-game collecting gaze measurements, where the threat of being hit exists, the limitation of on-ice testing drills not actually accounting for contact would be solved. A better study would involve eye-tracking during actual games for baseline and post-intervention testing, where participants have to be aware of other players on the ice and react accordingly. It could test Quickstickz training over the course of the season, monitoring improvements in players' gaze-up values and the correlation with hits received and injury rates. Separate data collection could include a camera collecting the game footage to provide objective video analysis of situations in which players were aware or unaware of incoming opponents, much like the Mihalek et al. study (21). This data could then be related to the gaze information, providing actual support linking the gaze-up behaviour and anticipation to hits and injuries.

Optimizing a study of this nature could also involve adapting the Quickstickz game itself to be more like an actual hockey game. Virtual opponents, or opponents on a life size screen like the volleyball gaze study, could be approaching and attempting to make contact with the player. The player would have to control the puck while avoid players on the screen by veering left or right. The volleyball study also suggested that adding verbal instruction and feedback from an instructor could help initiate gaze adjustments. It would be helpful to have participants come to the lab so that a research investigator or assistant is present to deliver this instruction and feedback. This would ensure appropriate training times and drills, and ensure compliance (24).

Adapting Quickstickz to enhance fidelity may include a change to other aspects of design, as Quickstickz is only really training puck control. Incorporating other skills into the game, such as shooting and skating, can possibly create a high fidelity training tool. There are projector screens used in golf simulators that track speed and direction of shooting that could be built into Quickstickz software. There are also skating treadmills that could control the speed of the game and approaching players. These changes would increase the price of the game and decrease the ability to be a home-based training solution, but may provide a training solution for a gym or training center.

Study Design

It has been established that certain drills be used in assessment as an alternative to live gameplay for ethical and logistical concerns. The drills chosen in this study were Hockey Canada standardized testing of skating, puck control and agility drills. It is possible that alternative drills that allow for more choices, and allow the player to be more creative, could better replicate gameplay. In a study involving soccer players, participants performed a number of passing drills with differing amounts of possibilities for passing actions. Ball speed and passing accuracy were measured by video analysis in each form of the drill and during games. The results of this study suggested that performance when more passing options were available related more closely to the competitive performance environment. Allowing players to act adaptively in practice would provide similar task conditions to gameplay, increasing fidelity (37). Designing the drills so that a player must react to unpredictable environmental stimuli, such as cueing sign or a projected image on a screen while skating and controlling the puck might be a better representation of gameplay while maintaining the safety and controlled environment.

Further research could involve a more detailed look at gaze behavior in the participants following training intervention. Other studies have used saccadic eye movements, which are quick shifts of the eyes to different fixation points, to assess gaze behaviour. The number of saccades down to the puck and back up could be measured, to investigate how often a participant required visual feedback in order to control the puck. The size of these eye movements could also be analyzed, to determine whether the player had to look directly at the puck, or if they only had to shift their gaze far enough that the puck was in their peripheral visual field. A region of interest analysis could also provide data on what players look at the most prior to and after training. This data may also be different for different participants depending on the stage of learning and level of play they are in. It would also be interesting to observe the attention required to control a puck and maintain the gaze-upward, versus other dual-task scenarios or even other sports (dribble a basketball and maintain an upwards gaze).

Recruitment consisted solely of elite 12-year old players, as they were about to enter into contact hockey. The premise was that these players would be more susceptible to injury at the elite level, with faster game speed and bigger and stronger opponents. As suggested earlier, analyses of individual data from the suggested that novice learners may benefit more from Quickstickz training than those who have mastered the skill of handling the puck with their head up. Including younger and less elite players in Quickstickz training may provide stronger improvements. Also, because this type of training is specific to skill level, more advanced drills or challenges on the Quickstickz game may benefit those athletes with higher baseline skill levels. Segregating players based on skill level for separate intervention training may lead to better outcomes in future studies.

The gaze-up training intervention is a pro-active approach in looking for new ways to prepare players for contact hockey in order to assist in concussion and injury avoidance. It is an innovative way to apply principles that have been around for a long time, but have not necessarily been focused to deliver proper training. Future adaptations of this study would do well to apply the principles and premise, in order to provide players with an established way to improve the gaze-up ability while controlling the puck.

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Appendix A: Consent Form

Parental Signature Page

Please address any question you or your child have about the study to the Principal Investigator either prior, during, or after your child's participation in the study. Once again, your child is free to withdraw from the study at any time without having to worry about any repercussions.

Study Title: Heads Up Hockey: Motor Control processes in the development of maintaining upward gaze while stick-handling

Summary: This study will investigate the efficacy of the Quickstickz game as a tool to teach young hockey players to keep their head up while stickhandling. The hypothesis is that, after a training intervention, gaze up time will increase while stick-handling, and that this will transfer toon-ice drills. Practical application will include more heads up time during practice and game play, allowing players to avoid contact and avoid injury, especially concussion.

Name of Principal Investigator: Ben MacAskill

Supervisor: Dr. David Westwood

Address: Dalhousie University Faculty of Health and Human Performance
Dalplex 6263 South Street
Halifax, Nova Scotia

University Telephone: (902) 494-1164

Email bn609897@dal.ca or david.westwood@dal.ca

"I (printed name), have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I hereby consent to take part in this study. However I realize that my child's participation is voluntary and that I am free to withdraw my child from the study at any time."

Parent/Guardian Signature:________________________ Date: ________________
Child Signature:_____________________ Date: _______________________
Principal Investigator's Name (Printed): _______________________
Principal Investigator's Signature: ____________________ Date: ______________

Participant assigned Code Number: _____________________

☐ Check this box if you would like to receive a copy of individual results.
☐ Check this box if you would like to receive a copy of study results.
Email Address:____

Appendix B: Recruitment Letters

Recruitment Letter for Coaches

Dear Coach,

My name is Ben MacAskill and I am a Kinesiology Graduate pursing a Masters Degree at Dalhousie University, with the supervision of Dr. David Westwood. I am emailing to see if you would be interested in having your players participate in my research project. The general purpose of my research is to determine the ability of Quickstickz to teach young players to keep their eyes up while stick-handling, to help avoid injury and to improve on-ice performance. Quickstickz uses a video game screen and a stickhandling ball equipped with video sensors to track stickhandling movements and relay them to on-screen drills. The participant must pay attention to the screen while performing stickhandling drills. My project has been reviewed and permitted to move forward by the Dalhousie Health Sciences Research Ethics Board. This project will be conducted through 3 on-ice testing sessions (at 0, 1 and 2 months), where the players will complete four drills while wearing an eye-tracking camera attached to the cage on their helmet. For one of the months in between testing sessions, half the players will be given the Quickstickz game to practice for 30 minutes a day, 4 times a week. The other month, half the players will participate in normal activities, without Quickstickz.

If you are interested, I request that you forward the message and recruitment letter I have attached, to the parents of your players regarding this project.

If you have any questions or concerns regarding the study please contact myself: Ben MacAskill, Masters Student, Kinesiology, Dalhousie University, email: bn609897@dal.ca my supervisor: Dr. David Westwood, Assistant Professor, Kinesiology, Dalhousie University, email: David.westwood@dal.ca, phone: 494-1164.

Thank you in advance,

Ben MacAskill

Recruitment Letter for Parents

Hello,

My name is Ben MacAskill and I am a Kinesiology Graduate student pursing a Masters Degree at Dalhousie University, with the supervision of Dr. David Westwood. I am emailing to invite you/your son to participate in my research project. The purpose of my research is to determine the ability of Quickstickz to teach young players to keep their eyes up while stick-handling, to help avoid injury and to improve on-ice performance. Quickstickz uses a video game screen and a stickhandling ball equipped with video sensors to track stickhandling movements and relay them to on-screen drills. The participant must pay attention to the screen while performing stickhandling drills. My project has been reviewed and permitted to move forward by the Dalhousie Health Sciences Research Ethics Board.

This project will be conducted through 3 on-ice testing sessions (at 0, 1 and 2 months), where you/your child will complete four drills while wearing an eye-tracking camera attached to the cage on their/your helmet. For one of the months in between testing sessions, they will be given the Quickstickz game to practice for 30 minutes a day, 4 times a week. The other month, they/you will participate in your normal activities, without Quickstickz.

If you/they are interested in participating in the study, or if you have any questions or concerns regarding the study please contact myself: Ben MacAskill, MSc, Kinesiology, Dalhousie University, email: bn609897@dal.ca or my supervisor: Dr. David Westwood, Assistant Professor, Kinesiology, Dalhousie University, email: David.westwood@dal.ca, phone: 494-1164.

Thank you in advance,

Ben MacAskill

Appendix C: Data Processing, Filters and Codes

Calibration

The middle row of dots on the calibration board are considered at horizontal gaze angle, and are given a value of 0 degrees. The upper and lower rows are +/-30 degrees gaze angle, respectively. The central dot corresponds to 0 degrees of vertical and horizontal eye angle, with the dot to the right and left corresponding to +30 and -30 degrees of horizontal angle. The dot above and below correspond to +30 and -30 degrees of vertical angle respectively.

By localizing the centre of the pupil in the camera image whilst fixating each of the 9 calibration points, it was possible to covert the pupil's location in the camera image at any point in time into a horizontal and vertical gaze angle by subtracting the X and Y coordinates of the central dot, and dividing by ratio of pixels/degree for the X and Y axes separately.

The stock lens that comes with this camera provides a wide-angle field of view. Images are captured in the infrared spectrum, where the pupil remains dark but both iris and skin tone becomes much lighter, as depicted in Figure 1a. The stock lens was replaced by a 12mm lens (Figure 1b), and an ambient filter was added (Figure 1c). An infrared light (Figure 1d) was also attached to the camera that makes the pupil clearer on the video image. The camera used a collecting rate of 15 frames per second at 4k, and the AG1 collected data at 40 Hz. The data were resampled for each to the smallest common multiple of their rates. For analysis, every 3rd sample from the camera and every 8th frame from the accelerometer were extracted.

Figure 18. Camera Image of Pupil in (a) down, (b) up, and (c) horizontal position.

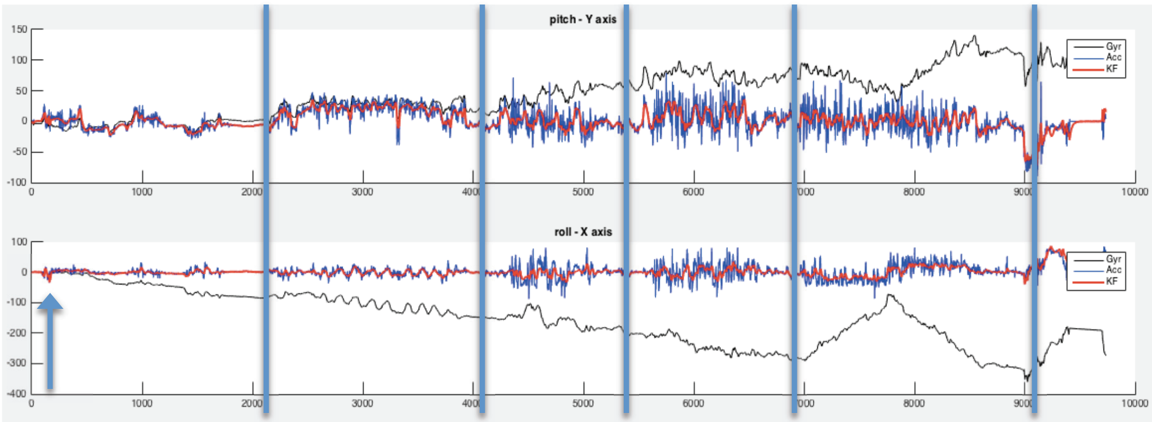


Figure 19. Gyrometer/Accelerometer Output, split by zeroing, synchronizing shake (arrow) and drills (sections 1, 2, 3, 4).

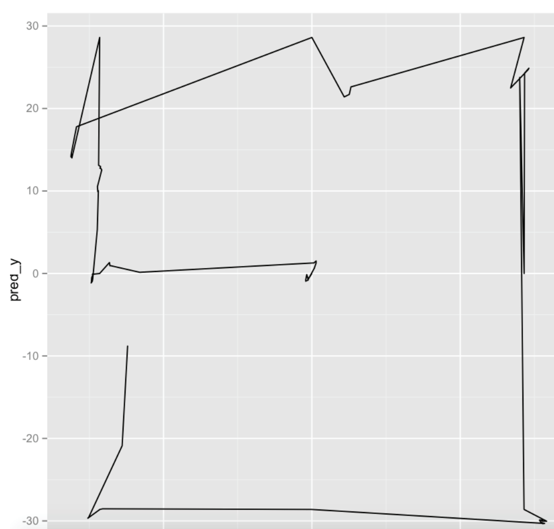


Figure 20. VidTracker output for Calibration. Degrees on y-axis. Line traced is the gaze path the pupil takes on the camera screen after processing.

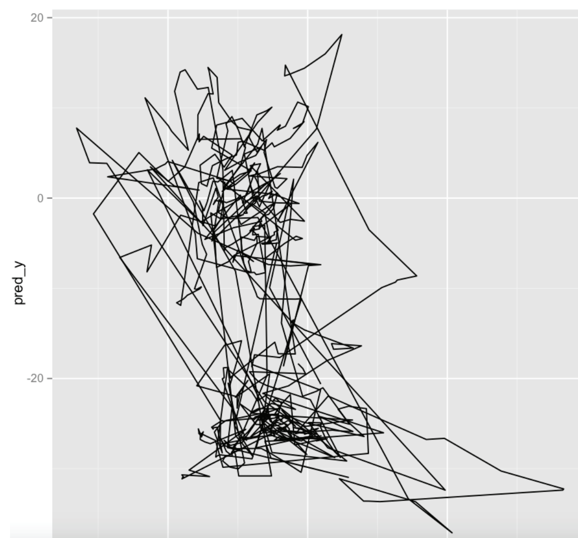


Figure 21. VidTracker eye-tracking example. Lines are the path the pupil takes on the camera screen after processing.

VidTracker

Once testing was complete, the video files were cut using iMovie to isolate the drills. The files were then loaded into Python VidTracker using Terminal. This software is able to track the movement of the pupil, identifying each frame and creating a file output that labels the on-screen coordinates where the pupil is located (based on pixels). This output file was loaded into 'R', a statistics software program. A code was written to convert the pupil coordinates into vertical gaze angle, based on the calibration equation, and using the three center dots on the calibration board as 0 degrees, the three upper dots as +30 degrees, and the three lower dots as -30 degrees.

For analysis of gaze direction from the resulting video and accelerometer data, a software package was developed in python using the OpenCV computer vision framework to locate and track the pupil in the video frame. These position data were then converted to angles using an R script. These data were combined with the Kalman filtered data (combines the accelerometer element and the gyrometer element to account for drifting) from the AG1 to calculate head angle. The code for the filters are shown below.

AG1 Data

Accelerometer/gyrometer data were sampled at 40 Hz and pupil position was sampled at 15 Hz. Each data series were resampled using the smallest common multiple of their sample rates (5 Hz) so that every third sample from the camera and every eighth sample from the accelerometer/gyrometer were included. To synchronize common time points in the two data streams, the accelerometer/gyrometer was placed on top of the camera and the combined unit was tapped three times. The data were then aligned using the spikes in motion detected in each system as a common zero-time point.

Deriving head-in-world angle from AG1 signals

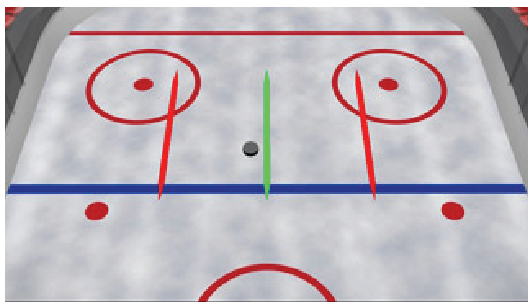
The AG1 data were cropped to isolate drills, and then imported into MatLab. A Kalman filter was applied to combine the acceleration data from the accelerometer (which are contaminated by linear accelerations of the head due to skating motion) with the angular velocity data from the accelerometer (which drift slowly over time) to form a better representation of head angle in the sagittal and frontal planes.

Head angle was then combined with gaze angle from the camera, and corrected for offset using the average head angle during camera calibration.

Appendix D: Quickstickz Drills

Soft Touch

The Soft Touch drill is the basic foundation drill that all future stickhandling drills are built on. You should perfect this skill before moving on to more complex drills. The key to this drill is soft hands and quick touches. You should focus on using just hands and wrists with very little arm movement. You should also cup the blade over the ball on both the forehand and backhand side when practicing this move.
You are awarded a point every time the ball is moved across the green line between the two red lines. You should use quick hands and soft touches to move ball back and forth across the green line. Should the ball cross either one of the red lines a point is deducted. You accumulate points by crossing the green line as many times as possible while avoiding the red lines.



Soft Touch Around Body

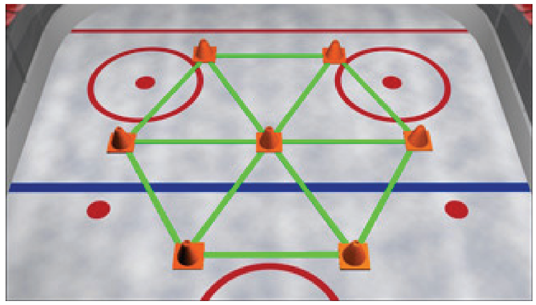
Once the basic Soft Touch technique has been mastered, you can then move on to a more difficult version of the drill by moving the ball around the body on both the forehand and backhand side. Again the key to this drill is soft hands, quick touches and very little arm movement. Your hands should be kept free and away from your body.

Stickhandle the ball between the red lines as they move in a semi-circle around your body. You are awarded a point every time the ball is moved across the green line between the two red lines. You should use quick hands and soft touches to move the ball back and forth across the green line. Should the ball cross either one of the red lines a point is deducted. You accumulate points by crossing the green line as many times as possible while avoiding the red lines.

Soft Touch Random

This is the final drill in the Soft Touch series. It is still important to use soft hands, quick touches and very little arm movement. Your hands should be kept free and away from your body.

Stickhandle the ball between the red lines as they randomly move in a semi-circle around your body. You are awarded a point every time the ball is moved across the green line between the two red lines. You should use quick hands and soft touches to move the ball back and forth across the green line. Should the ball cross either one of the red lines a point is deducted. You accumulate points by crossing the green line as many times as possible while avoiding the red lines.



Obstacle Course

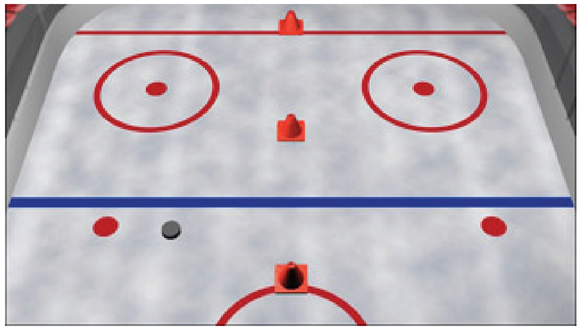
The object of this drill is to work on your quick hands, agility, and hand-eye coordination. Maneuver the onscreen puck through and around the pylons, crossing each green line. When all green lines have been crossed, they will all reappear and you continue to cross them and make them disappear. You are awarded a point for every green line crossed and is deducted a point if a pylon is hit. Cross the green lines as many times as you can in the allotted time.

Targets

You'll need to use quick, soft touches to move the onscreen puck around to hit targets as they randomly appear. As a target appears, stickhandle the onscreen puck to hit them. As they explode, another target will randomly appear. You receive a point for every target hit. Hit as many targets as you can in the allotted time.

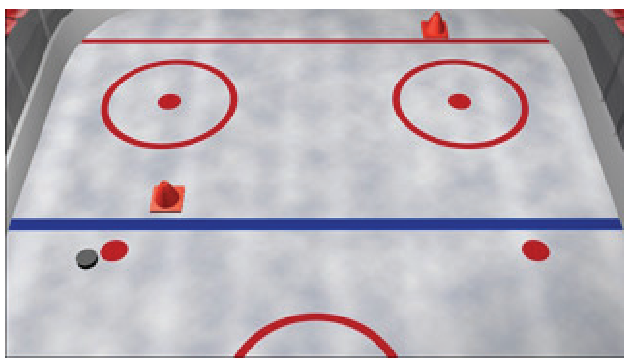
Narrow Dribble

The object of this drill is to work on hand speed and quick wrist action. You should cup ball on both the backhand and forehand side of the stick. By doing so this allows you to control the ball at all times. Light touches and quick dribbles are key to success. As the onscreen pylons descend and move toward the bottom, move the onscreen puck between the pylons. Each time you are successful in doing so, a point is awarded. Should you hit a pylon, a point is deducted. Stickhandle between as many pylons as possible in the allotted time.



Wide Dribble

The object of this drill is to work on loose bottom hand, hand slide and expansion of reach. When the ball is extended at maximum distance away from your body to allow it to go around onscreen pylons, your hands should be close together. As the ball is pulled across your body to the other side, your hands spread wide and then back together to allow maximum reach to move ball around the pylon on the opposite side. As the onscreen pylons descend and move toward the bottom, move the onscreen puck around the pylons. Each time you are successful in doing so, a point is awarded. Should you hit a pylon, a point is deducted. Stickhandle around as many pylons as possible in the allotted time.



Combination Dribble

You'll need to use the skills you have learned from both the Narrow Dribble and Wide Dribble drills to be successful in this drill. As the onscreen pylons descend and move toward the bottom, move the onscreen puck through or around the pylons. Each time you are successful in doing so, a point is awarded. Should you hit a pylon, a point is deducted. Stickhandle through or around as many pylons as possible in the allotted time.

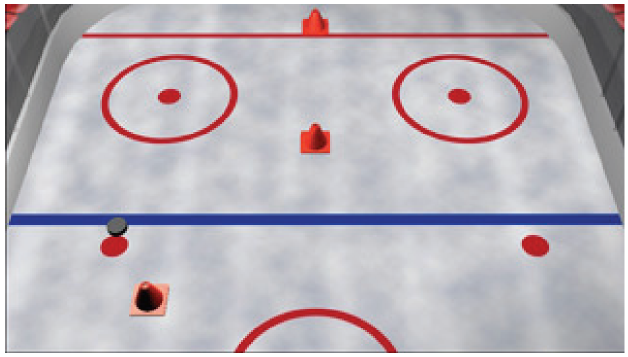
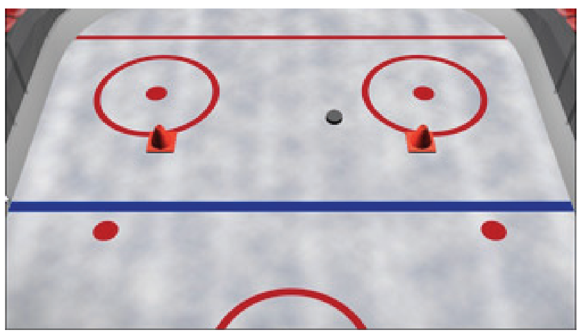


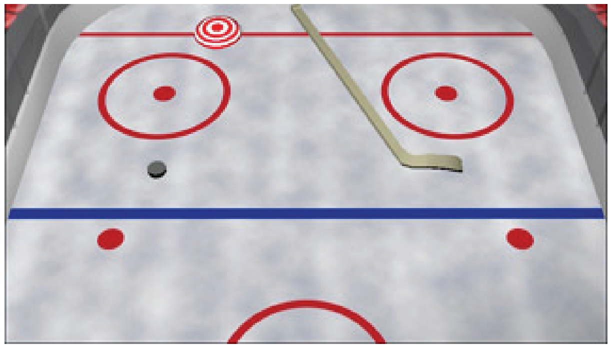
Figure-8

Continue to work on a loose bottom hand slide and expansion of reach while working on the skill of pulling the ball diagonally across your body. As you move the ball around the on screen pylons, you must use both the heel and toe of the stick to perform the drill correctly. As you move the ball around the pylons in a figure 8 pattern, a point is awarded each time the ball is successfully stickhandled around the pylon and crosses the centre line. Should you hit a pylon or not go completely around the pylon, a point is deducted.



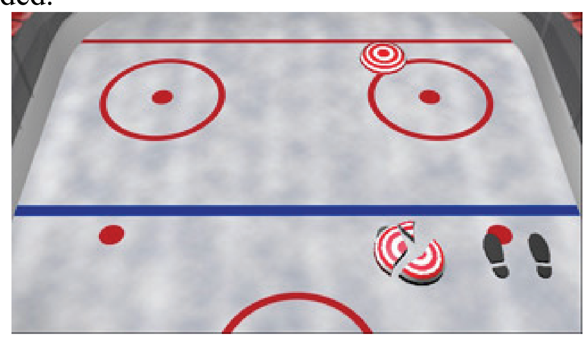
Windshield Wiper

Work on the hand slide on the stick as well as on a push-pull move using the toe and heel of the stick blade. When the ball is in tight, your hands are wide. The ball is pushed out forward with the heel of the stick as your hands slide together. It is then stopped with the toe of the blade and pulled back toward your body. The same process is used to move the ball out to your forehand side.
Strike the targets as they appear without coming in contact with the stick as it swings from side to side. A point is awarded for each target struck and a point is deducted for every time the swinging stick hits the puck onscreen.



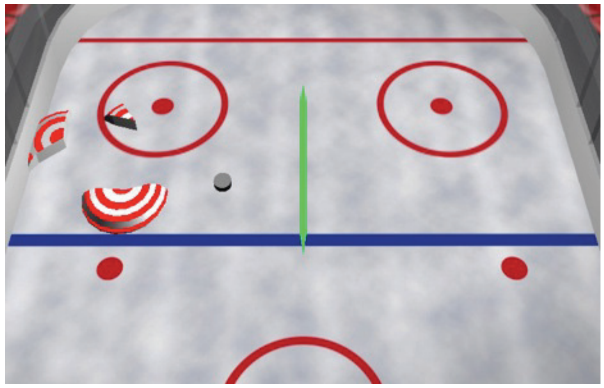
Yo-Yo

This drill continues to work on the hand slide on the stick as well as working on a push-pull move using the toe and heel of the stick blade. When the ball is in tight, your hands are wide. The ball is pushed out forward with the heel of the stick as your hands slide together. It is then stopped with the toe of the blade and pulled back toward your body. The same process is used to move the ball out to your forehand side. You must move the ball out to the side and up to the front to strike the targets. Each time a target is struck, a point is awarded.



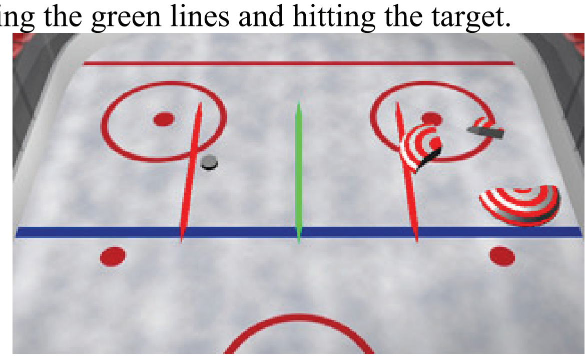
Front Forehand Fake

The Front Forehand Fake is one of the first moves a hockey player learns. It is also one that is used continuously throughout a game. It is a basic move that has three main steps to it. The first step is to dribble the ball directly in front of your body. The second step is to make a quick movement (a fake) to your backhand side. You accomplish this by dipping your head, dropping your shoulder, bending your leg and moving the ball in line with your bent leg. To finish the move, you immediately move the ball from that position, across your body and wide as possible to your forehand. These are the three basic steps to the Front Forehand Fake. The QuickStickz Front Forehand Fake trains the player to practice each step properly with their head up. To begin the drill, dribble the ball across the centre green line. After you have crossed it several times, it will disappear and another green line will appear on your backhand side. Pull the ball across your body and cross that green line. Remember to dip your head, drop your shoulder and bend your leg. Once the ball crosses the green line on your backhand side, it will disappear and a target will appear on your forehand side. Quickly bring the ball back across your body and hit the target. Once the target is hit, the green line appears in the middle again and you are ready to repeat the move. Points are accumulated by crossing the green lines and hitting the target.



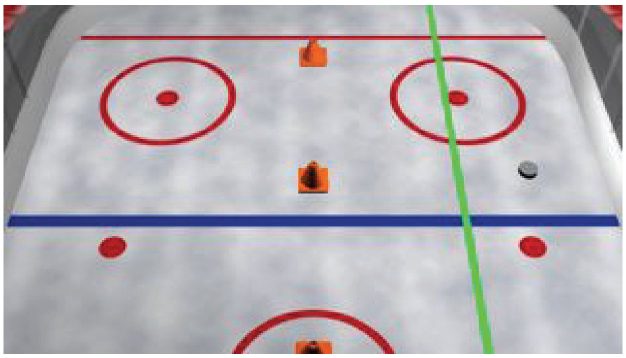
Front Backhand Fake

The Front Backhand Fake has all the same steps as the Front Forehand Fake except they are done on the opposite side of the body. Players seem to be more comfortable with this move and use it even more in game situations. The first step is to dribble the ball directly in front of your body. The second step is to make a quick movement (a fake) to your forehand side. You accomplish this by dipping your head, dropping your shoulder, bending your leg and moving the ball in line with your bent leg. To finish the move, you immediately move the ball from that position, across your body and wide as possible to your backhand. Most players when they make this fake, drop their bottom hand off the stick which allows for even greater separation between them and their opponent. These are the three basic steps to the Front Backhand Fake. The QuickStickz Front Backhand Fake trains the player to practice each step properly with their head up. To begin the drill, dribble the ball across the centre green line. After you have crossed it several times, it will disappear and another green line will appear on your forehand side. Pull the ball across your body and cross that green line. Remember to dip your head, drop your shoulder and bend your leg. Once the ball crosses the green line on your forehand side, it will disappear and a target will appear on your backhand side. Quickly bring the ball back across your body and hit the target. Once the target is hit, the green line appears in the middle again and you are ready to repeat the move. Points are accumulated by crossing the green lines and hitting the target.



Narrow Dribble / Soft Touch

Like the name suggests, we have combined two drills into one very challenging drill that works on two very important skills. Players have to move the ball quickly from side to side through the pylons using good hand/eye coordination. Once through the pylons, player must then use soft quick touches to gain even more points by stickhandling quickly back and forth over green line. Then it's back through the pylons and repeated soft quick touches on the other side. Player is awarded a point every time the ball is passed through the pylons and is also awarded additional points when the ball is dribbled back and forth across the green lines on each side. Should player hit a pylon, a point is deducted. Stickhandle between as many pylons and across the green lines as many times as possible in the allotted time.



Triangle Targets

This drill forces the player to move the ball away from their body, across their body and then back to starting position creating a triangle pattern. Player starts with a few quick dribbles, moves ball away from their body with the front part of their blade to the upper target. Once there, a few quick dribbles and then player quickly pulls ball across body to opposite corner target. Another couple of quick dribbles and then player pulls ball toward them with back of blade to starting position. A couple quick dribbles and then pattern is repeated. Object of drill is to move ball as quick as you can around the triangle pattern and hit as many targets as possible in the allotted time.