Exploring the Acute Affect of De-Coupled Batting Drills on the Gaze Behaviour and Decision-Making of Elite Baseball Players

By

Matthew McCue

A thesis submitted to the
School of Graduate and Postdoctoral Studies in partial
fulfillment of the requirements for the degree of

Masters of Health Sciences

Faculty of Health Sciences

Kinesiology

University of Ontario Institute of Technology

Oshawa, Ontario, Canada

July 2019

THESIS EXAMINATION INFORMATION

Submitted by: **Matthew McCue**

Master of Health Sciences

Thesis title: **Exploring the Acute Affect of De-Coupled Batting Drills on the Gaze Behaviour and Decision-Making of Elite Baseball Players**

An oral defense of this thesis took place on July 8, 2019 in front of the following examining committee:

Examining Committee:

Chair of Examining Committee	Dr. Manon Lemonde
Research Supervisor	Dr. Nick Wattie
Examining Committee Member	Dr. Heather Sprenger
Thesis Examiner	Dr. Bernadette Murphy, OTU

The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

Expert batters utilize context-specific information and gaze behaviour to aid decision-making and performance. However, typical practice and warm-up activities often lack relevant context-specific information and visual cues that exist in competition. This study's purpose was to examine if drills varying in competition representativeness have an acute influence on decision-making and gaze behaviour. Twenty-eight elite baseball athletes participated in one of four warm-up drills and subsequently predicted pitch information in an 18 pitch simulation over three progressively harder temporal occlusion conditions. Main effects of occlusion time, $F = 5.43, 3.87$; $p = .01, .03$, and playing level, t = 2.41, $p = .02$; $F = 13.06$, $p = .003$, were observed in decision-making and gaze behaviour analyses, but no statistically significant warm-up condition effects were noted. Players of advanced skill made more correct predictions and fixated on task relevant areas, which was amplified by earlier occlusion times. The lack of a warm-up condition effect may be explained by the athletes' prolonged exposure to unrepresentative practice activities and their subsequent skill in recalibration at switching between tasks.

Keywords: perceptual-cognitive skill; representative learning design; high performance sport; perception-action coupling.

AUTHOR'S DECLARATION

I hereby declare that this thesis consists of original work of which I have authored. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I authorize the University of Ontario Institute of Technology to lend this thesis to other institutions or individuals for the purpose of scholarly research. I further authorize University of Ontario Institute of Technology to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research. I understand that my thesis will be made electronically available to the public.

The research work in this thesis that was performed in compliance with the regulations of UOIT's Research Ethics Board under **REB Certificate #14950.**

Matt McCue

____ MATTHEW McCUE

STATEMENT OF CONTRIBUTIONS

I hereby certify that I am the sole author of this thesis and that no part of this thesis has been published or submitted for publication. I have used standard referencing practices to acknowledge ideas, research techniques, or other materials that belong to others. Furthermore, with support from my supervisor, I hereby certify that I am the sole source of the creative works and/or inventive knowledge described in this thesis. Part of the work described in Chapter 3 has been or will be presented by me as:

McCue, M & Wattie, N. (2018, March). Assessing the affect of de-coupled batting drills on the gaze behaviour of elite baseball players. Verbal presentation at the 22nd annual Eastern Canada Sport and Exercise Psychology Symposium: An AASP International Conference. Montreal, Quebec, Canada.

McCue, M & Wattie, N. (2019, March). Evaluating the affect of batting drills on the decision-making and performance of elite baseball players. Verbal presentation at the 23rd annual Eastern Canada Sport and Exercise Psychology Symposium: An AASP International conference. Markham, Ontario, Canada.

McCue, M & Wattie, N. (2019, July). An exploration of the relationship between representativeness of warm-up drills and performance in elite baseball players. Poster presentation at the 15th European Congress of Sport & Exercise Psychology. Münster, Germany.

ACKNOWLEDGEMENTS

The culmination of this thesis would not have been possible without the support and guidance from a number of individuals. I would first like to thank my supervisor, Dr. Nick Wattie, for taking a chance on a washed-up baseball player. Your counsel throughout the entire process was invaluable and your passion for research is contagious. Despite the infamous track changes (i.e., '???') and poor taste in sports teams, I am extremely grateful for your supervision, and look forward to our future research endeavors.

I would also like to thank Dr. Heather Sprenger, Dr. Bernadette Murphy, and Dr. Joseph Baker for their help and input on this thesis. Additionally, thank you to Ian Barker and Ryan Foley, whose timely support was crucial during data collection. To my colleagues in the Wattie lab, Jason 'Sprouts' Mergler, Annie 'Corral' Pietroniro, Arman 'Conference Casual' Mohammadi, and Lou 'Content Creator' Farah: Thank you for always providing valuable feedback and for enduring my bad jokes. I consider you all great friends.

Finally, I would like to thank my ever-growing family. Thank you to my grandparents and parents, whose unflappability and encouragement to pursue happiness were the key determinants of my involvement in this project. I would also like to thank my brothers; your compassionate personalities (evident from the countless beat downs you allow me to serve you in fantasy baseball and other various sports) are the crutches I rely on when I am overwhelmed. And of course, thank you to my girlfriend, Emily McCallen. Your steadfast support and uncanny ability to reinvigorate my drive for my goals were the catalysts in the completion of this project. I cannot imagine chasing down our collective goals with a better partner.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

Fix*f*	Duration of final fixation
MLB	Major League Baseball
NAIA	National Association of Intercollegiate Athletics
NCAA	National College Athletic Association
NJCAA	National Junior College Athletic Association
RLD	Representative learning design
RLE	Representative leaning environment
SMI	SensoMotoric Instruments
TtRPFix	Time to Release Point Fixation

Chapter 1. Introduction

The development of elite-level athletic performance is a multifaceted process that relies on the interaction of numerous factors. A combination of inherent ability, acquirable skills, physiological demands, and financial constraints must be considered when attempting to optimize athlete development (Baker & Horton, 2004; Wattie & Baker, 2018). Those that attain expert levels of performance are affected by these factors in a variable manner (i.e., family wealth may relegate financial constraints as insignificant), yet all performers must invariably engage in one common activity: practice. Practice, which is deemed to be a critical component of sport expertise (see, for comprehensive reviews of this topic, Baker & Farrow, 2015; Baker & Young, 2014; Starkes & Ericsson, 2003), functions both as an activity that influences performance and a key differentiator between skill levels. As athletes amass more practice hours, they are able to refine their abilities and begin to advance or progress through the skill continuum. As such, researchers and coaches are able to use the total volume of domain-specific practice, typically in hours, as a key differentiator between skill levels (see, Baker, Cobley, & Fraser-Thomas, 2009). While accumulated practice in sport is undoubtedly important and necessary (Helsen, Starkes, & Hodges, 1998), research suggests that there is significant variation in accumulated practice between elite-level athletes (Baker et al., 2009; Hambrick et al., 2014). As such, one must consider *how* practice is structured and designed to truly comprehend the significant impact it may have on learning and performance.

Recent research suggests that implementing practice tasks that are more representative of competition positively influences skill acquisition and performance (Rosalie & Muller, 2012). Representative learning environments enable 'perception-action coupling', the pairing of movements (i.e., actions) with the necessary contextual and perceptual information needed to successfully execute a task. For example, a tennis player couples the visual information that is supplied by a ball at its peak height during a service toss (perception) with the appropriate movement pattern (action) that is needed to make contact. A practice regime may not be viewed as a representative learning environment (low in representativeness) if it emphasizes task decomposition and the integration of drills devoid of competition specific information. Practicing unrepresentative movement patterns, or without necessary contextual information, does not provide ample opportunity for the development of perception-action coupling. This concept has been applied to the lack of benefits associated with breaking the volleyball and tennis serve into constituent parts during practice (Whiteside, Giblin & Reid, 2017; Davids et al., 2001). The constraint of using a ball machine to simulate an actual opponent may also hinder the development of perception-action coupling as it causes significantly different spatiotemporal kinematics in a batter's swing (Pinder, Renshaw & Davids, 2009). Moreover, the use of ball machines in the practice environment have been shown to impact reaction times. Shim et al. (2005) measured differences in reaction latencies when expert tennis players attempted to return serves from a ball machine or live opponent (Shim, Carlton, Chow, & Chae, 2005). The reaction to a live opponent was significantly faster than the reaction to a ball machine. The players' ability to anticipate shot direction results as they amass relevant cues from their opponent's movement pattern. When a ball machine is used in the practice environment, players are not able to develop this skill. Despite the abundance of research focused on drill design and biomechanics, there remains a dearth of literature that focuses on the potential impact drill design may have on perceptual-cognitive skill.

Perceptual-cognitive skill in part describes the ability to inform decision-making and anticipation with the processing of task relevant cues (Broadbent, Causer, Williams, & Ford, 2015; Mann, Williams, Ward, & Janelle, 2007; Marteniuk, 1976) which is crucial to the success of high performance athletes. The development and demonstration of perceptual-cognitive skill is thought to be highly domain specific and the result of extensive accumulated practice. An efficient visual search strategy or gaze behaviour (e.g. location and number of fixation points, and gaze duration) is a major component of perceptual-cognitive skill and is required to effectively extract task relevant cues from the dynamic and information rich sporting environment. The importance of gaze behaviour in various sporting domains is well documented (Croft, Button, & Dicks, 2010; Hayhoe, McKinney, Chajka, & Pelz, 2012; Hubbard & Seng, 1954), yet the influence of representative practice and warm-up on gaze behaviour remains relatively unexplored.

As athletes progress towards elite levels, they are taught a variety of warm-up and practice drills that prioritize consistent performance (Farrow, Baker, & MacMahon, 2013). Decades of research has delineated our understanding of expertise, and how it differs from novice behaviours (Ericsson, 2014; Ericsson & Smith, 1991; Starkes & Ericsson, 2003). However, drills that are incorporated at the grass roots levels may still be used by experts in that domain. For instance, the stationary tee drill in baseball requires the batter to repetitively swing at a ball that is propped up in a desired location. This drill may be used to teach fundamentals to novices or by experts striving to make mechanical adjustments to their swings. Although there is an obvious disparity between an expert and novice hitter, they both must consider how the design of this drill aligns with their intended goal. When desirable movement outcomes and skill transfer to competition are the primary goals, drills high in representativeness have been recommended (Krause, Farrow, Reid, Buszard, & Pinder, 2017). The relationship between drill representativeness and competition performance has been assessed in the practice environment (far-transfer) suggesting that this effect may be more pronounced in a warm-up environment (near-transfer).

Warming-up prior to physical activity is a widely accepted routine that has positive applications for a variety of physiological and neural mechanisms (McGowan, Pyne, Thompson, & Rattray, 2015). Ajemian et al. (2010) proposed that elite athletes participating in sports that require fine motor skills (i.e., interceptive sports) may benefit from prolonged warm-up periods for reasons beyond preparing relevant muscles and tendons. The framework proposed by these authors suggest that the warm-up period is necessary as the athlete must recalibrate the sensorimotor system to ensure optimal performance. The two assumptions of this framework, the high noise level and learning rates of the human sensorimotor network system, suggest that a de-coupled (unrepresentative) warm-up routine may perturb the calibration of fine perceptual-motor skills. To my knowledge, the relationship between sensorimotor network calibration and representative learning design has not been explored.

Batting in baseball has been identified as one of the most challenging perceptual-cognitive-motor tasks in interceptive sports. Thus, it is optimal for exploring the convergence of the aforementioned concepts. In order to successfully strike a baseball, a batter must pair complex spatiotemporal kinematics with relevant perceptual and contextual information. Despite this complexity, the common practice and warm-up environment in baseball involves activities that are ‘de-coupled’. For example, although batters extract valuable information from pitchers’ hand and arm movements, typical warm-up and practice drills contain none of this competition specific information. Additionally, Mann et al. (2013) discovered that professional batters have an elite ability to couple the rotation of their heard with the velocity of an approaching ball. Yet a common drill in baseball, use of a ball mounted on a stationary tee, requires the athlete to practice a swing with their head stationary and gaze fixated on one location. The prevalence of these drills in the practice and warm-up environment provides an ideal opportunity to explore the relationship between representative learning environments and perceptual-cognitive performance. Therefore, the purpose of this study is to examine the influence of warm-up batting drills, each with different degrees of ‘de-coupling’ from competition, through analysis of athlete gaze behaviour and decision-making.

Research Question

Does participation in drills that are de-coupled or unrepresentative have an acute influence on the gaze behaviour and performance of elite baseball players?

We hypothesize that drills more representative of hitting in a game situation preserve perception-action coupling and will therefore elicit more positive gaze behaviours and decision-making.

References

Ajemian, R., D'Ausilio, A., Moorman, H., & Bizzi, E. (2010). Why professional athletes need a prolonged period of warm-up and other peculiarities of human motor learning. *Journal of Motor Behavior, 42*(6), 381-388.

Baker, J., Cobley, S., & Fraser-Thomas, J. (2009). What do we know about early sport specialization? Not much! *High ability studies*, *20*(1), 77-89.

Baker, J., & Farrow, D. (2015). *Routledge handbook of sport expertise*: Routledge.

Baker, J., & Horton, S. (2004). A review of primary and secondary influences on sport expertise. *High ability studies*, *15*(2), 211-228.

Baker, J., & Young, B. (2014). 20 years later: Deliberate practice and the development of expertise in sport. *International Review of Sport and Exercise Psychology, 7*(1), 135-157.

Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. R. (2015). Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *European journal of sport science, 15*(4), 322-331.

Croft, J., Button, C., & Dicks, M. (2010). Visual strategies of sub-elite cricket batsmen in response to different ball velocities. *Human Movement Science*, *29*(5), 751-763.

Ericsson, K. A. (2014). *The road to excellence: The acquisition of expert performance in the arts and sciences, sports, and games*: Psychology Press.

Ericsson, K. A., & Smith, J. (1991). *Toward a general theory of expertise: Prospects and limits*: Cambridge University Press.

Farrow, D., Baker, J., & MacMahon, C. (2013). *Developing sport expertise: Researchers and coaches put theory into practice*: Routledge.

Hambrick, D. Z., Oswald, F. L., Altmann, E. M., Meinz, E. J., Gobet, F., & Campitelli, G. (2014). Deliberate practice: Is that all it takes to become an expert? *Intelligence, 45*, 34-45.

Hayhoe, M. M., McKinney, T., Chajka, K., & Pelz, J. B. (2012). Predictive eye movements in natural vision. *Experimental brain research, 217*(1), 125-136.

Helsen, W. F., Starkes, J. L., & Hodges, N. J. (1998). Team sports and the theory of deliberate practice. *Journal of Sport and Exercise Psychology, 20*(1), 12-34.

Hubbard, A. W., & Seng, C. N. (1954). Visual movements of batters. *Research Quarterly. American Association for Health, Physical Education and Recreation, 25*(1), 42-57.

Krause, L., Farrow, D., Reid, M., Buszard, T., & Pinder, R. (2017). Helping coaches apply the principles of representative learning design: validation of a tennis specific practice assessment tool. *Journal of Sports Sciences*, 1-10.

Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology, 29*(4), 457-478.

Marteniuk, R. G. (1976). *Information processing in motor skills*: Holt, Rinehart and Winston.

McGowan, C. J., Pyne, D. B., Thompson, K. G., & Rattray, B. (2015). Warm-up strategies for sport and exercise: mechanisms and applications. *Sports Medicine, 45*(11), 1523-1546.

Starkes, J. L., & Ericsson, K. A. (2003). *Expert performance in sports: Advances in research on sport expertise*: Human Kinetics.

Wattie, N., & Baker, J. (2018). An uneven playing field: Talent identification systems and the perpetuation of participation biases in high performance sport. In *Sport and Physical Activity across the Lifespan* (pp. 117-133): Springer.

Chapter 2. Literature Review

2.1 Expertise & Expert Performance

Experts possess the ability to perform difficult tasks with a mastery and consistency that provokes an admiration. The abilities and impressive performances of musicians, artists, and athletes are praised and scrutinized under the watchful eyes of millions via traditional and social media outlets. Moreover, society rewards expertise in many disciplines with idolization and lucrative financial remuneration. Despite a relatively simple conceptualization of what expertise may be (see: Baker, Wattie, & Schorer, 2015), decades of research has striven to classify levels of performance, and identify characteristics that are frequently displayed by experts.

Early research in this area compared chess players with varying degrees of skill in an attempt to identify attributes that were explicitly demonstrated by the elite competitors (Chase & Simon, 1973; De Groot, 1965). Highly skilled chess players, when compared to lesser skilled chess players, were able to extract and recall more information about chess piece positioning with a shorter exposure time (De Groot, 1965). Although these novel findings suggested a difference of skills as a function of expertise, it was still unclear if highly skilled chess players needed to naturally possess advanced memory abilities to excel or if this could be developed. Chase and Simon (1973) expounded on this concept by presenting configurations of chess pieces typically seen in a match as well as random configurations to players with varying skill. True to the original findings, highly skilled players were able to reproduce the configurations of pieces more accurately when they represented common game positioning. However, expertise level did not lead to apparent differences in recall accuracy when random game configurations were used, suggesting that chess masters were not naturally endowed with advanced memory skills but relied on superior domain-specific pattern recognition.

Once elite skills were delineated in chess masters, researchers began to explore expertise in other domains. This burgeoning area of research began to identify an array of characteristics that only belonged to superior performers and attempted to ascribe innate capabilities as the predominant differentiator of experts from novices. For example, Keele and Hawkins (1982) explored the possibility that general capabilities may account for differences in fast action motor-skill through the assessment of hypothetical abilities: time-sharing and attentional allocation. Conceivably, the ability to multi-task while maintaining the flexibility to rapidly switch attention between sources may be crucial to success in fast-paced sports. However, no evidence was found for a general time-sharing ability, and modest evidence was presented with a number of potential confounding variables for attentional allocation. Subsequently, Starkes (1987) conducted a more comprehensive comparison of innate and domain-specific abilities in field hockey players. The results indicated that the only variables that predicted skill level were domain-specific, and learned from many years of playing experience. For example, experts performed significantly better in their abilities to recall relevant game-structure information and to predict final shot placement after ball impact was shown. However, with the sheer vastness of possible factors that may predict expertise (cognitive ability, body composition, environment etc.), and the nuances of superior performance in numerous domains, it became apparent that a theoretical framework was needed to explain the origin of domain-specific skill and expertise.

Ericsson and Smith (1991) proposed such an approach and coined it 'the expertise approach'. The two main features of this framework involved the use of representative tasks (domain-specific) that could identify superior performance in standardized conditions and empirical analyses of the key processes used by experts to complete the tasks (Ericsson & Smith, 1991). This regulated approach strengthened the reliability of expertise research and allowed researchers to analyze how these key factors may be acquired. Thus, the expert vs novice paradigm began to flourish.

As discernible differences were noted between expert and novice skills, research began to shift towards an explanation for how these expert traits may be developed. Anders Ericsson and colleagues (1993) proposed a theoretical framework for the acquisition of expert performance suggesting that expertise development is far more complex than the fruition of natural abilities. This framework was primarily centered around the benefits of 'deliberate practice', defined as highly structured activities that are specifically designed to improve performance, are inherently unenjoyable, require energy, and do not lead to immediate rewards (Ericsson, Krampe, & Tesch-Römer, 1993). Furthermore, it was suggested that accumulated deliberate practice hours were the primary determinant of expertise development as they were proposed to be monotonically related to performance in skilled tasks. Expertise development as a function of deliberate practice has been widely debated (Baker & Davids, 2006; Epstein, 2014; Tucker & Collins, 2012), but it has had an undeniable, ever-lasting impact on the scientific community and the role of the training environment in sport expertise development (Baker & Young, 2014). However, a notable criticism of the theory of deliberate practice is that it does little to inform *how* practice should be designed, and *what* should be practiced.

Literature suggests that study designs emphasizing domain-specificity via the preservation of perception-action couplings (the pairing of information and movement, see page 3), accentuate the differences between expert and lesser skilled athletes. Farrow and Abernathy (2003) used expert and novice tennis players to demonstrate this concept. Athletes were separated into two conditions with differing degrees of perception-action coupling, and told to predict the location of an opponent's serve. The uncoupled group verbally predicted service direction while the coupled group incorporated a "movement-based response" (P. 1127) with their prediction. The movement-based response required the participant to perform the exact same movements that they would use in a game to return a serve. Experts displayed significantly better accuracy than novices in the coupled condition. However, experts and novices' prediction accuracy was not significantly different in the uncoupled response condition. This finding suggested that experts pair sensory information of an approaching ball with the corresponding movement to achieve successful interception. When the action is disassociated from the perception (i.e., de-coupled) the expert advantage in perceptual cognitive skill diminishes. Experts are able to differentiate themselves when perception-action couplings are better preserved as they are more representative of the competition environments where they developed the aforementioned calibration of perceptual-cognitive skills. This is fundamental to the concept of representative learning design, but also to considering the quality and characteristics of deliberate practice activities.

The focus of this thesis is the influence of representative learning designs on batting performance in baseball. In interceptive sport tasks, such as batting in baseball, as athletes attempt to strike a moving object they must pair sensory information with the appropriate motor coordination. Elite hitters routinely engage in a complex perception-action coupling, yet the typical practice and warm-up environment in baseball involves activities that are de-coupled. As stated earlier, the lack of benefits associated with de-coupled practice have been shown in cricket (Pinder, Renshaw, & Davids, 2009), tennis (Reid, Whiteside, & Elliott, 2010; Whiteside, Giblin, & Reid, 2014) and volleyball (Davids, Kingsbury, Bennett, & Handford, 2001) via alterations in swing kinematics and negative effects to extrinsic timing behavior. However, the possible disruption of de-coupled practice on gaze behavior and performance has not been explored.

The purpose of the following sections is to review the literature that is integral to perceptual-cognitive skill and skill acquisition research. Specifically, this review will focus on literature assessing perceptual-cognitive skill, representative learning design and the dynamic visual abilities of expert batters in interceptive sports. Fundamental concepts and existing gaps in the literature will be identified to demonstrate the demand for additional research.

2.2 Perceptual-cognitive skill in high performance sport

Athletes that are successful in a high performance setting rely on their unique assortment of physical, emotional, and mental capabilities to excel. Physical parameters that identify how experts differ from novices are readily available with quantitative skill measurements (i.e., the velocity of a tennis serve/baseball pitch, top speed of a sprinter, maximum vertical jump of a basketball player). However, a true understanding of the disparity between skill levels stems from a consideration of a range of skills, including perceptual and cognitive factors. Indeed, analyses of expertise in sport suggests that experts are able to recognize and process more significant game information (Allard, Graham, & Paarsalu, 1980; Ripoll, 1991; Starkes, 1987) and possess more strategic knowledge than lesser skilled athletes (French & Thomas, 1987; McPherson, 1993; McPherson & Thomas, 1989). This information may then be used to inform future decisions or movements (Abernethy, 1986, 1990; Müller & Abernethy, 2012). To explore these principles, many researchers rely on temporal occlusion experimental designs, which involves the editing of an image or video so that the stimulus is blacked-out (i.e., occluded) at a predetermined time. The stimulus image or video is typically filmed from the player's perspective and presented to participants with the intention to preserve game-like situations (Farrow, Abernethy, & Jackson, 2005). Researchers may use the decision-making results from temporal occlusion studies to gain valuable insight about specific mechanisms that inform perceptual-cognitive skill. For example, Abernethy et al. (2001) used a temporal occlusion design to demonstrate the anticipative qualities that expert squash players possess. Experts, in comparison to the novices, assessed their opponents' pre-contact kinematics and used this information to predict shot direction with more accuracy (Abernethy, Gill, Parks, & Packer, 2001). Moreover, the experts were able to use situational probabilities and their opponents' previous patterns more effectively when relevant pre-contact information was not available.

An expert athlete that is adept at anticipating may also use this information to bolster decision-making. The ability to predict or anticipate events in a competition is undoubtedly an advantage, but experts must couple that information with accurate movements. For example, a soccer goal keeper may anticipate the location of a pass crossing into the crease, but they still must choose the appropriate movements (i.e., punch/catch the ball or stay in position) to make a save. Roca et al. (2013) demonstrated this interaction of anticipation and decision-making in skilled and less skilled soccer defenders. Participants wore a mobile eye tracker and were presented with video simulations of a soccer competition that were temporally occluded directly before the offender made a decision (i.e., pass, shoot, and/or dribble). Anticipation performance was determined by the participants' ability to correctly predict the next action made by the opposition, while decision-making performance relied on their ability to execute the most appropriate decision as a defender (i.e., challenge ball handler, close in on off-ball opponent, and block shot). Unsurprisingly, skilled players were more accurate in their anticipation and decision-making than lesser skilled players. The difference in these predictions were underpinned by significantly different gaze behaviours, a finding that is well documented in perceptual-cognitive skill research.

Gaze behaviour research

The gaze behaviour of athletes has been a topic of interest since technological developments have allowed researchers to track them. Eye-trackers were first used to assess the gaze behaviour of basketball players in the 1970s (Bard & Fleury, 1976). These players differed in their level of expertise and demonstrated significantly different fixation behaviour as they reacted to cards depicting basketball scenarios. This seminal study revealed stark differences in expert and novice gaze behaviour. The key findings suggested that experts allocate visual fixations to fewer locations and for a longer period of time. Although these findings have been questioned for external validity (the athletes reacting to pictures is not the most accurate simulation of a game) they suggested the notion that highly advanced domain-specific gaze behaviour may be a crucial characteristic of expert performance and perceptual-cognitive skill. This motivated researchers to explore inter-individual disparities in visual attention and even intra-individual differences while performing a task.

The differences in expert and lesser skilled performers' gaze behaviour have been supported in a wide variety of domains through empirical work. Two meta-analyses, Mann et al. (2007) and Gegenfurtner et al. (2011), as well as Kredel et al.'s (2017) systematic review, have synthesized the major differences in visual search behaviours. A fundamental takeaway from empirical data is that experts are able to prioritize their vision to locations that supply the richest perceptual information. Experts will initiate fixation on task-relevant areas quicker and hold their gaze on this location for longer durations when compared to novices (Gegenfurtner et al., 2011; Mann et al., 2007). Findings suggest that when experts are provided with domain-specific information, they are able to draw from perceptual-cognitive skills developed over years of experience to exploit contextual and strategic information (Baker & Farrow, 2015).

The use of effective visual search strategies by experts was analyzed in a study of cricket batters performing a simulated anticipation task (McRobert, Ward, Eccles, & Williams, 2011). Skilled and less skilled batters were instructed to view and respond to a simulated bowler while their eye movements, response accuracy, and think-aloud protocol were recorded. Batters also perceived the stimuli in high and low context conditions that differed in consecutive trials of the same pitcher (i.e., high context condition involved viewing the same bowler for more consecutive pitches than the low context condition). The skilled batters fixated on task-relevant areas such as the bowling arm, trunk-hip, and predicted release point while less skilled batters "spent more time focusing primarily on the ball-hand location as well as on less relevant unclassified locations" (P. 530). Additionally, skilled batters were able to reduce their mean fixation duration in the high compared to low context condition while less skilled participants did not see a significant difference across context conditions. McRobert and colleagues suggested that the skilled players were able to reduce their mean fixation duration in the high context condition as the additional contextual information allowed them to process relevant information more efficiently. This refined search behaviour of the skilled batters, coupled with a shortened initiation of fixation on the ball release point, gave them earlier insight to the flight path of the ball. This would certainly be advantageous in sports like cricket and baseball where a hitter's reaction to a ball's spin, velocity, and trajectory is vital for success and highly time-constrained.

Millslagle et al. (2013) built on the previous findings through gaze behaviour analysis of expert and near-expert umpires. McRobert et al. (2011) noted the use of a simulated pitcher and a think-aloud protocol as two limitations. In an effort to address this, the umpires observed live pitchers and called balls and strikes just as they would in a game. Their gaze behaviour is used to evaluate the final location of a pitch, similar to that of a hitter or a catcher attempting to predict final pitch location. Expert umpires were superior in their ability to track the ball and fixate on the location where the ball was released from. This was delineated by a longer duration and earlier onset of ball tracking. These findings suggest that expert umpires, like expert hitters (Kato & Fukuda, 2002; Takeuchi & Inomata, 2009), employ advanced search behaviours to effectively assess where a pitch is going to cross the plate. Thus, in combination with McRobert et al. (2011), inter-individual differences in gaze behaviour rely on advanced anticipative and perceptual techniques. Expert athletes are able to fixate on task-relevant cues quicker, for a longer duration, and do not focus on as many task-irrelevant areas compared to lesser skilled athletes. Additionally, these techniques are used to predict the release point of a moving object and employ superior ball tracking ability to assess the final location of the ball.

Limitations of gaze behaviour research

The most prominent limitation in current gaze behaviour research is the use of a device to track eye-movements. Athletes must wear some type of device or stand close enough to a camera in order to track small variations of eye movement. This integration of a device undoubtedly effects the natural gaze behaviour of athletes, no matter how naturalistic the study design may be. Fortunately, advances in technology have considerably increased reliability of the cameras used and led to reductions in the size and weight of mobile eye trackers. Kredel et al. (2017) discuss these limitations and identify four main objectives of sports related eye-tracking research. Two main objectives focused on ensuring *ecological validity* with ‘realistic viewing conditions’ and the inclusion of ‘real-world movements.’ These objectives must be considered when assessing how representative the study is of the environment researchers are attempting to simulate. The final two stress the importance of *experimental control* through optimization of ‘precise measurements’ and ‘gaze-data analysis.’ Researchers must balance these two themes while developing sound study design. For example, a seated study with cutting edge eye-tracking technology provides opportunity for maximizing *experimental control*. However, the findings may not be generalized to real-world sports as sitting in a chair may not be representative of a high performance environment and thus the *ecological validity* of such a study would be lower. This proposed trade-off remains quite difficult to circumvent as modern technology has not developed to a point where entirely non-obstructive eye-trackers exist. Researchers must be cognizant of this reality and account for it during data analysis.

Various gaze behaviour studies structured around gaze interventions have attempted to support the *ecological validity* and *experimental control* of their study designs by collecting competition statistics. This method may be the most effective for capturing the ecological validity of an intervention as it supports the notion that the intervention may have had a far-transfer of skill. However, it is difficult to infer the effectiveness of such an intervention as a variety of confounding variables may be present. An illustration of this concept is captured by the research done in association with the University of Cincinnati baseball team. Players on the team received high performance vision training (intervention), and their statistics were recorded over two season (Clark, Ellis, Bench, Khoury, & Graman, 2012). Conclusions on the effectiveness of the intervention were made solely on increases in batting average, slugging percentage, and on-base percentage when compared to the rest of the conference they played in. Relying on these statistics to claim intervention effectiveness does not account for: change due to non-intervention-related deliberate practice, amount of starters returning, average age of the team (more seniors or more freshmen), pitching staff talent of the University of Cincinnati (perhaps their pitchers perform better the following year and lower the average of the rest of the conference), loss of an exceptional hitter on one team, increase in close games, and many other variables that may skew the three statistics analyzed. Thus, this study was lacking the necessary *experimental control* needed to claim the overall effectiveness of the gaze-training intervention.

Addressing the potential limitations that arise in gaze behaviour research is crucial when analyzing and communicating results. A study design that includes all the movements and visuals that are typically included in a competition environment may be highly representative or *ecologically valid*. However, a study that includes game-like movements has the potential to be limited in *experimental control* as these movements may cause calibration issues or may only be possible with costly mobile eye trackers. Furthermore, the robustness of findings in gaze behaviour research may be supported by including a plethora of perceptual-cognitive skill variables. For instance, studies that collect gaze behaviour data concurrently with additional outcome variables (i.e., shot/pitch prediction or game-structure recall) are able to analyze critical interactions between gaze behaviour and perceptual-cognitive skill. Minor variations that arise in outcome variables may have substantial implications for athletes in a high performance context where the room for error is minimal. Therefore, researchers using eye tracking technology in high performance sport must balance the trade-off between *ecological validity* and *experimental control* in study design and consider the robustness and limitations of their findings when communicating results.

2.3 Competition representation in the practice environment

Although gaze behaviour, and perceptual-cognitive skill, are of paramount importance to athletes participating in interceptive sport, the elite practice environment does not always nurture this skill with relevant drills. Coaches, constrained by time and resources, typically shift their focus to developing a consistent motor skill set with tasks that disregard competition-specific information (Farrow, Baker, & MacMahon, 2013; Krause, Farrow, Reid, Buszard, & Pinder, 2017). This tactic of coaching abides by the deliberate practice framework (Ericsson et al., 1993), but recent research suggests that it may not encourage skill transfer to game situations. The argument for decreased skill transfer opportunities stems from the lack of perception-action coupling preservation, or a deviation from the framework known as Representative Learning Design (RLD). This framework is proposed to represent the degree to which a practice or study design represents a situation or competition (Pinder, Davids, Renshaw, & Araújo, 2011). The importance of domain-specific practice for acquiring domain-specific skill has consistently been demonstrated throughout training environment and expertise research (Helsen & Starkes, 1999; Starkes & Ericsson, 2003). When assessing the representativeness of competition in sport, two key terms that comprise RLD must be considered: functionality and action fidelity (Krause et al., 2017; Pinder, Renshaw, Davids, & Kerhervé, 2011). Functionality refers to the extent that an athlete may use informational cues that are present during completion to inform decisions and movement (Pinder, Renshaw, et al., 2011). For example, the curveball drill used in baseball (a ball is bounced to a batter to simulate the arc of a curveball) would be low in functionality as the batter must process visual information (a bouncing ball) that is not typically seen in competition. Action fidelity refers to the extent that an athlete's movement behaviour during a task or drill mimics the required movement behaviour during competition (Araujo, Davids, & Passos, 2007). A drill low in action fidelity may be identified in softball when a hitter repeatedly practices their swing from a load position (without transferring weight) to infer benefits for hand path through the zone. Krause et al. (2017) used the concepts of functionality and action fidelity to develop a "Representative Practice Assessment Tool" that allows coaches to assess the representativeness of their drills (Krause et al., 2017). This tool provides a way of quantifying the degree of perception-action coupling in practice or study design. The following section will outline research that has assessed the functionality and action fidelity of various drills or practice tasks, draw comparisons to calibration research, and delve into the importance of RLD when skill acquisition is the primary goal.

Decomposing a task into constituent parts

The ball toss drill in volleyball and tennis has been a recent focal point for researchers exploring perception-action coupling preservation in the practice environment. When the serve is broken into constituent parts and the ball toss is practiced in isolation, athletes may not be afforded the opportunity to develop key information-movement couplings. Davids et al. (2001) explored this principle in novice volleyball players. Players were divided into two interventions: a service condition (serving task included a ball toss followed by striking of the ball) and a placement condition (ball toss practiced in isolation). These interventions were conducted in-between a pre- and post-test assessing service accuracy where ball zenith (highest point) was recorded. The placement group represents a common drill used by volleyball coaches where players are instructed to consistently place their ball 18 inches above their shoulder. Findings suggest that there were two key differences between conditions: "variance of ball zenith was less for serving condition and mean ball zenith was greater in the placement-only condition"

(P. 124). These were significant findings as expert volleyball players couple hip movement with ball zenith (Davids, 1999). This information-movement coupling is a crucial development for novice volleyball players and thus practicing the ball toss without movement yields no benefit. Additionally, practicing the ball toss in isolation may develop a higher average ball zenith, increasing the chance of error at the point of contact. Similar findings were noted in tennis players (Reid et al., 2010; Whiteside et al., 2014). Consistency of the ball toss was found to decrease when it was practiced in isolation. This decomposition of the serve may prove to be harmful to the developing volleyball or tennis player. Moreover, perhaps practicing tasks for interceptive sports like baseball in an environment that disturbs the development of information-movement coupling is acutely harmful to a batter's ability to execute a swing, and to long-term skill development.

Obscuring movement-pattern information with a ball machine

The use of a ball machine in the practice environment is an additional drill that coaches may be inadvertently using to develop undesirable movements, gaze behaviour, and perceptual-cognitive skills. Shim et al. (2005) measured differences in reaction latencies when expert tennis players attempted to return serves from a ball machine or live opponent (Shim, Carlton, Chow, & Chae, 2005). The reaction to a live opponent was significantly faster than the reaction to a ball machine. The players' ability to anticipate shot direction results as they amass relevant cues from their opponent's movement pattern. When a ball machine was used in the practice environment, players were not able to develop this skill. Similar effects of ball machine use on developing cricketers have been observed. Pinder et al. (2009) mapped differences in spatiotemporal kinematics when batters responded to a ball machine and live opponent in a counterbalanced design. Significant differences in initiation of key phases of the swing, front foot movement, backswing, and kinematics were observed. In a highly dynamical task of intercepting a bowl or pitch, minor differences in swing pattern have substantial effects. In support of Shim et al.'s (2005) findings, these batters were unable to extract valuable pre-bowl cues from the bowling machine. As a result, the novice batters were denied the sensory information necessary to the coupling between ball release and initiation of the backswing. Therefore, maintaining competition representation in the tennis and cricket practice environment is crucial for developing players.

Calibration and recalibration of fine motor skills

The link between RLD and performance may also be illustrated with calibration and recalibration literature. This research suggests that the human perceptual-motor system, similar to measurement instruments, needs to be calibrated to ensure accuracy when performing skilled actions. Brand and de Oliveira (2017) identified attunement, calibration, and recalibration as the three main processes used by individuals striving to optimize the accuracy of fine motor skills. Attunement, also known the education of attention (Gibson, 1963; Gibson & Gibson, 1955), is a method of perceptual learning where a person attempts to discern the key information variables that will guide a successful action (Brand & de Oliveira, 2017). For instance, baseball batters may experience attunement when they face a pitcher for the first time. Expert batters rely on key perceptual variables displayed by the pitcher (i.e., typical release point and movement/velocity of the pitches) to successfully track a ball (Kato & Fukuda, 2002; Takeuchi & Inomata, 2009). The batter may attune to the information supplied by the pitcher after facing a number of pitches (although the time-frame for this attunement process has not been explored in the literature) to guide the appropriate visual search patterns.

Following attunement, a person performing a complex motor skill must calibrate or scale their action capabilities to the appropriate perceptual information (Brand & de Oliveira, 2017; van Andel, Cole, & Pepping, 2017; Withagen & Michaels, 2002). This process is known as calibration in ecological psychology literature, which intuitively links to perception-action coupling processes. A skilled action may be well-calibrated when a strong link between perception and action is made by the performer. Despite this straightforward definition of calibration, it is often confused with recalibration in perceptual-motor literature (see, Brand & de Oliveira, 2017, for a review). Recalibration may only occur if a disturbance perturbs the calibration between perception and action (Brand & de Oliveira, 2017). Disturbances may affect the perception (i.e., obscuring visual information via occlusion) or action (i.e., altering the weight of a cricket bat). The previously stated research into the effects of ball-machine use in cricket and baseball are pertinent depictions of a disturbance to the batters' perception. Batters that are well-calibrated may need to go through a process of recalibration after facing the ball machine as the lack of context specific information (pitcher wind-up) renders the perception-action link inaccurate. Thus, whether you classify drills low in representativeness as de-coupled or disturbances, the lingering affect these tasks may have on the sensorimotor networks of skilled performers is an imperative area of research.

Drill effectiveness literature in baseball

As mentioned in previous sections, a variety of studies have assessed drill effectiveness in volleyball, tennis and cricket. Undoubtedly, experts in these sports require an optimal synthesis of advanced gaze behaviour and hand-eye coordination. The vast majority of these studies focus primarily on the negative kinematic effects of task decomposition or the undesirable movements produced by tasks devoid of competition-specific information. Although success in these sports require similar perceptual and motor demands as baseball, there remains a dearth of literature that explores how practice drills may impact a batter. In one of the only studies to assess a practice intervention, Fadde (2006) did attempt to train pitch recognition in NCAA college baseball players. A treatment group received pitch recognition training for a two week period while a control group attended normal pre-season practice sessions. The treatment group was exposed to nine interactive sessions where they observed videos of a pitcher delivering a pitch and were required to predict the pitch type and location. Players advanced to the next stage when they predicted a certain number of pitches right and each stage got progressively harder via earlier temporal occlusion (i.e., less ball flight was shown until no ball flight was shown at all). Game hitting performance was treated as the dependent variable and was broken into batting average (i.e., hitting success rate), on-base percentage, and slugging percentage. The batting average of the treatment group was significantly higher than the control group over an 18-game span, while the other metrics were not significantly different. The application of progressive temporal occlusion as a training intervention for pitch type recognition in baseball hitters was innovative. However, when competition statistics are not supplemented with dependent measures observed in a controlled setting, a desirable extent of experimental control is difficult to achieve. To mitigate concerns over experimental control and assess the veracity of a pitch type recognition intervention via progressive temporal occlusion, future research could incorporate gaze behaviour or decision-making data.

Although there has been little exploration of drill effectiveness in baseball practice and warm-up, Gray has substantially contributed to the understanding of how batters employ perceptual-motor control to successfully intercept the ball. Gray has used the perception-action coupling paradigm and developed novel study designs to evaluate how players use perceptual information to inform anticipation and movement patterns. For example, a batter's swing in an at-bat is significantly influenced by previous pitches (i.e., velocity and trajectory) and the situation (pitch count and game script) (Gray, 2002). This may be demonstrated by a batter that uses physical cues, such as where the ball contacted the bat (i.e., off the end of the bat or closer to their hands), to determine if their prediction about pitch type and location was correct. This information may be used in a subsequent at-bat. Furthermore, players with less experience have been shown to be influenced more by previous pitches, suggesting that more skilled players are able to use perceptual information to confirm or deny their expectations about the approaching pitch (Gray, 2009c). The batter may develop expectations about the upcoming pitch based off of indirect information such as subtle hints from a pitcher's body language, previous experience against said pitcher, and their domain-specific knowledge of what pitch might be thrown in particular game situations (Gray, 2009b). Direct information, including visual judgements of an approaching pitch (see: Gray, 2009b, for an extensive modeling of this process) and sensory feedback (tactile, visual and auditory) from bat-ball contact (Gray, 2009a) is then used to assess the accuracy of their prediction.

Recently, Gray (2017) has built off this comprehensive work in baseball batting and perceptual-motor skill and shifted research towards the training environment and virtual reality. Specifically, an adaptive virtual reality training environment has been used to improve the performance of skilled high school baseball players. One of the virtual environments (VE) used in the intervention was designed to have agreeability with the "challenge point hypothesis" (Guadagnoli & Lee, 2004) as pitches in this condition were manipulated to correspond with skill level (i.e., the pitch speed and area of pitch location only increased after each successful swing). Additionally, this intervention accounted for variability in the practice environment as each batter faced a random sequence of pitches. In comparison to the three other training interventions used in this study (see Gray 2017), batters that participated in the adaptive VE showed significantly greater improvements in final performance scores and league play batting statistics. The near and far transfer of adaptive VE training to on-field performance demonstrated in this study suggests that there is certainly utility of VEs in the practice environment. However, the high cost and complexity of the technology involved may serve as a barrier for interested coaches and researchers. Future research should strive to replicate these findings in training interventions or drills that are commonly used in every day practice.

The extensive research Gray has conducted on baseball batting has been informed our current understanding of how a hitter uses various sensory information and decision-making to inform the appropriate motor coordination. Despite contributing to our understanding of hitting a baseball, there remains a gap in the literature. It is not clear if, or what, the acute influence of drills is on these complex processes. In order to understand how the representativeness of a drill may influence the gaze behaviour and performance of a batter, it is essential to consider the intricacies of the mechanisms involved.

2.4 How expert batters use eye movements to intercept a ball

The fastest pitchers in Major League Baseball (MLB) are able to produce velocities of approximately 100 mph. The resulting angular velocity of this type of pitch tops 500 °/ second. The human eye is unable to track a target moving faster than 70°/ second (Schalen, 1980), suggesting the adage " keep your eye on the ball" is impossible. Somehow, an MLB batter is able to overcome this limitation and strike a spherical ball with a cone-like object. Bahill and LaRtiz (1984) conducted the first laboratory study attempting to measure how a professional baseball player is able to track a pitch. Participants assumed the same batting stance that they would use in a game and were told to track a ball that was affixed to a fishing line. The ball approached the same location every time and reached velocities between 60-100 mph with the help of a motor. Eye and head movements were monitored with an eye-tracker and external cameras and were compared to the position of the approaching ball. The professional athlete used in the study was able to maintain a position error below 2° until the ball reached 5.5 feet in front of the plate. From this point, a saccadic eye movement (a rapid jump from one fixation point to the next) was used to predict where the pitch would cross the plate. Further, his head and eye movements were coordinated while tracking the ball. The ability to track with your eyes must be matched by the rotation of your head. Since a batter must start their swing 175 milliseconds before contact is made (Adair, 2002) the advantage of an eye saccade to observe bat contact may purely be educational; The batter can use this information of pitch finality as a source of feedback and calibration in future at bats. A few obvious limitations to this study include small sample size, a disregard for perception-action coupling (batters did not swing a bat), and the simulation did not allow the batter to use pitcher cues to anticipate final pitch location.

Professional cricket batters face similar velocities yet their burdened with having to react to the ball before and after it bounces in front of them. A major distinction of professional batters from club batters is their ability to couple the rotation of their head with the movement of the ball (Mann, Spratford, & Abernethy, 2013). Club batters differentiate in this regard as they will attempt to couple eye movements with the movement of the ball. This difference is important to note as professional batters would rather use their eye movements to make predictive saccades. Two saccades are typically made by professionals attempting to strike a ball: one to the predicted location of the ball bounce and a second to predict bat-ball contact. A latency in the first saccade has been shown to distinguish elite from lesser skilled batters (Land & McLeod, 2000). The combination of head –ball coupling and predictive saccadic movements are the major components of a professional batsman’s swing. Despite this knowledge, these skills are not typically targeted for talent identification purposes (draft selection or scholarship offers) or accounted for through practice and drill design. The focus of elite athlete development and talent identification heavily emphasizes outcome variables (i.e., exit velocity and/or launch angle of a ball after bat-ball contact) yet the major predictors of these outcomes (i.e., the ability to couple head and ball and to make predictive saccades) are often overlooked.

As mentioned earlier, elite batters use these dynamical visual abilities during ball flight in combination with the capability to extract pre-pitch information from a pitcher's movements. McRobert et al. (2011) demonstrated this concept via manipulations of contextual information as they tracked the fixations of a cricket batter's gaze before a bowler released a ball. The context was manipulated so that there were two conditions differing in their representation of an actual match. The low contextual condition faced a random order of video simulated pitches delivered by multiple bowlers (not representative of a match). Contrastingly, the high contextual condition attempted to directly represent match conditions so that each participant faced the same simulated bowler in blocks of six. Skilled players were able to "reduce their mean fixation time when they viewed their opponent multiple times" (P. 520). McRobert et al. (2011) suggested that these experts were able to adjust their search strategy pre-pitch as they knew the natural progression of the bowler's delivery. Years earlier, McPherson (1993) qualitatively explored this ability to anticipate via decision-making. Experts differed from novices in this study by their ability to constantly update action-plan goals. They were able to analyze a pitcher's characteristics and use this information to predict what type of pitch they were going to see in an at-bat.

This extraordinary visual ability during ball flight and decision-making capacity pre-pitch has fascinated researchers for decades. The next step for eye-tracking sports related research is to hone in on the development of these skills. A logical suggestion would be to shift focus towards the practice environment and how these elite visual abilities are learned. For example, three drills encompass traditional batting practice in baseball: tee-work, pitching machine batting practice, and coach thrown batting practice

(Kagan, 2017). The argument can certainly be made that all three drills differ in degree of competition representation (functionality and action fidelity). Tee-work denotes the least game-like drill as a batter is deprived of pitcher relevant cues, head rotation and saccadic eye movements, and key timing aspects such as release point. Pitching machine batting practice addresses two of these limitations but the negative effects associated with ball machine use have been highlighted by Shim et al. (2005) and Pinder et al. (2011). Finally, receiving batting practice from a coach represents the most game-like drill as a batter may practice extracting relevant pre-pitch data while subsequently developing the head-ball coupling. Baseball players that span the skill continuum have these three drills entrenched in their typical practice and warm-up routine but may not be aware of their potential impact. The inherent de-coupling of each drill and how it may influence the extremely complex perceptual-motor mechanisms professionals have developed, or pre-elites are attempting to develop, should certainly be explored.

2.5 Conclusion

In summary, this review has distinguished expert from lesser skilled gaze behaviour, demonstrated the importance of competition representation and perceptual-cognitive skill development in the practice environment, and depicted how expert batters employ advanced eye movements to strike a ball. A common theme found in the literature was the vitality of perception-action coupling preservation. Ecological validity was strengthened in studies that made this is a priority and drill effectiveness was bolstered when this was kept in-tact. However, there remains a dearth of literature examining the design of warm-up and practice drills and their acute affect on the decision-making and gaze behaviour abilities of athletes. Research indicates that the practice environment emphasizing task decomposition and the integration of drills devoid of competition specific information does not provide ample opportunity for the development of information-movement coupling. The lack of benefits associated with decoupled drill integration to the practice environment has been validated through swing alterations of spatiotemporal kinematics and inconsistent ball zenith development. However, the possible disruption of decoupled practice on gaze behavior and performance has not been explored. Such a study may have important implications for skill acquisition and talent identification research. Elite coaches and development programs may use these findings to develop innovative pedagogical methods. Further, findings might influence training in a variety of performance contexts that strive to augment skill transfer from practice to performance, such as sports, health care, first responders and the military.

2.6 References

Abernethy, B. (1986). Anticipation in sport: A review. *Physical education review, 10*(1), 5-16.

Abernethy, B. (1990). Expertise, visual search, and information pick-up in squash. *Perception, 19*(1), 63-77.

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception, 30*(2), 233-252.

Adair, R. K. (2002). *The Physics ofBaseball*: HarperCollins, New York.

Allard, F., Graham, S., & Paarsalu, M. E. (1980). Perception in sport: Basketball. *Journal of sport psychology, 2*(1), 14-21.

Araujo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: Comment on. *Ecological Psychology, 19*(1), 69-78.

Bahill, A. T., & LaRitz, T. (1984). Why can't batters keep their eyes on the ball. *American Scientist, 72*(3), 249-253.

Baker, J., & Davids, K. (2006). Genetic and environmental constraints on variability in sport performance. *Movement system variability*, 109-132.

Baker, J., & Farrow, D. (2015). *Routledge handbook of sport expertise*: Routledge.

Baker, J., Wattie, N., & Schorer, J. (2015). A taxonomy for researchers in skill acquisition and expertise. In *Routledge handbook of sport expertise* (pp. 145-155).

Baker, J., & Young, B. (2014). 20 years later: Deliberate practice and the development of expertise in sport. *International Review of Sport and Exercise Psychology, 7*(1), 135-157.

Bard, C., & Fleury, M. (1976). Analysis of visual search activity during sport problem situations. *Journal of Human Movement Studies, 3*(2), 214-222.

Brand, M. T., & de Oliveira, R. F. (2017). Recalibration in functional perceptual-motor tasks: A systematic review. *Human Movement Science, 56*, 54-70.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive psychology, 4*(1), 55-81.

Clark, J. F., Ellis, J. K., Bench, J., Khoury, J., & Graman, P. (2012). High-performance vision training improves batting statistics for University of Cincinnati baseball players. *PloS one, 7*(1), e29109.

Davids, K., Bennett, S.J., Handford, C.H. and Jones, B. (1999). Acquiring a frame of reference for practising in selfpaced extrinsic timing tasks: Analysis of co-ordination in skilled volleyballers. *International Journal of Sport Psychology, 30*, 437-461.

Davids, K., Kingsbury, D., Bennett, S., & Handford, C. (2001). Information-movement coupling: Implications for the organization of research and practice during acquisition of self-paced extrinsic timing skills. *Journal of Sports Sciences, 19*(2), 117-127.

De Groot, A. D. (1965). *Thought and choice in chess* (Vol. 4): Walter de Gruyter GmbH & Co KG.

Epstein, D. (2014). *The sports gene: Inside the science of extraordinary athletic performance*: Penguin.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological review, 100*(3), 363.

Ericsson, K. A., & Smith, J. (1991). *Toward a general theory of expertise: Prospects and limits*: Cambridge University Press.

Fadde, P. J. (2006). Interactive video training of perceptual decision-making in the sport of baseball. *Technology, Instruction, Cognition and Learning, 4*(3), 265-285.

Farrow, D., & Abernethy, B. (2003). Do expertise and the degree of perception—action coupling affect natural anticipatory performance? *Perception, 32*(9), 1127-1139.

Farrow, D., Abernethy, B., & Jackson, R. C. (2005). Probing expert anticipation with the temporal occlusion paradigm: Experimental investigations of some methodological issues. *Motor control, 9*(3), 330-349.

Farrow, D., Baker, J., & MacMahon, C. (2013). *Developing sport expertise: Researchers and coaches put theory into practice*: Routledge.

French, K. E., & Thomas, J. R. (1987). The Relation off Knowledge Development to Children's Basketball Performance. *Journal of sport psychology, 9*(1), 15-32.

Gegenfurtner, A., Lehtinen, E., & Säljö, R. (2011). Expertise differences in the comprehension of visualizations: A meta-analysis of eye-tracking research in professional domains. *Educational Psychology Review, 23*(4), 523-552.

Gibson, E. J. (1963). Perceptual learning. *Annual review of psychology, 14*(1), 29-56.

Gibson, J. J., & Gibson, E. J. (1955). Perceptual learning: Differentiation or enrichment? *Psychological review, 62*(1), 32.

Gray, R. (2002). Behavior of college baseball players in a virtual batting task. *Journal of Experimental Psychology: Human Perception and Performance*, *28*(5), 1131.

Gray, R. (2009a). How do batters use visual, auditory, and tactile information about the success of a baseball swing? *Research Quarterly for Exercise and Sport, 80*(3), 491-501.

Gray, R. (2009b). Intercepting moving objects: Fundamental principles learned from baseball. *Reviews of human factors and ergonomics, 5*(1), 114-139.

Gray, R. (2009c). A model of motor inhibition for a complex skill: Baseball batting. *Journal of Experimental Psychology: Applied, 15*(2), 91.

Gray, R. (2017). Transfer of Training from Virtual to Real Baseball Batting. *Frontiers in Psychology*, *8*(2183). doi:10.3389/fpsyg.2017.02183

Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning. *Journal of Motor Behavior, 36*(2), 212-224.

Helsen, W. F., & Starkes, J. L. (1999). A multidimensional approach to skilled perception and performance in sport. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition, 13*(1), 1-27.

Kagan, D. (2017). The Physics of Batting Practice. Retrieved from https://www.fangraphs.com/tht/the-physics-of-batting-practice/

Kato, T., & Fukuda, T. (2002). Visual search strategies of baseball batters: eye movements during the preparatory phase of batting. *Perceptual and Motor Skills, 94*(2), 380-386.

Keele, S. W., & Hawkins, H. L. (1982). Explorations of Individual Differences Relevant to High Level Skill. *Journal of Motor Behavior, 14*(1), 3-23.

Krause, L., Farrow, D., Reid, M., Buszard, T., & Pinder, R. (2017). Helping coaches apply the principles of representative learning design: validation of a tennis specific practice assessment tool. *Journal of Sports Sciences*, 1-10.

Kredel, R., Vater, C., Klostermann, A., & Hossner, E.-J. (2017). Eye-Tracking Technology and the Dynamics of Natural Gaze Behavior in Sports: A Systematic Review of 40 Years of Research. *Frontiers in Psychology, 8*(1845). doi:10.3389/fpsyg.2017.01845

Land, M. F., & McLeod, P. (2000). From eye movements to actions: how batsmen hit the ball. *Nature neuroscience, 3*(12), 1340-1345.

Mann, D. L., Spratford, W., & Abernethy, B. (2013). The head tracks and gaze predicts: how the world's best batters hit a ball. *PloS one, 8*(3), e58289.

Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology, 29*(4), 457-478.

McPherson, S. L. (1993). The influence of player experience on problem solving during batting preparation in baseball. *Journal of Sport and Exercise Psychology, 15*(3), 304-325.

McPherson, S. L., & Thomas, J. R. (1989). Relation of knowledge and performance in boys' tennis: Age and expertise. *Journal of experimental child psychology, 48*(2), 190-211.

McRobert, A. P., Ward, P., Eccles, D. W., & Williams, A. M. (2011). The effect of manipulating context-specific information on perceptual–cognitive processes during a simulated anticipation task. *British Journal of Psychology, 102*(3), 519-534.

Millslagle, D. G., Hines, B. B., & Smith, M. S. (2013). Quiet Eye Gaze Behavior of Expert, and Near-Expert, Baseball Plate Umpires. *Perceptual and Motor Skills, 116*(1), 69-77. doi:10.2466/24.22.27.PMS.116.1.69-77

Müller, S., & Abernethy, B. (2012). Expert anticipatory skill in striking sports: A review and a model. *Research Quarterly for Exercise and Sport, 83*(2), 175-187.

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology, 33*(1), 146-155.

Pinder, R. A., Renshaw, I., & Davids, K. (2009). Information–movement coupling in developing cricketers under changing ecological practice constraints. *Human Movement Science, 28*(4), 468-479.

Pinder, R. A., Renshaw, I., Davids, K., & Kerhervé, H. (2011). Principles for the use of ball projection machines in elite and developmental sport programmes. *Sports Medicine, 41*(10), 793-800.

Reid, M., Whiteside, D., & Elliott, B. (2010). Effect of skill decomposition on racket and ball kinematics of the elite junior tennis serve. *Sports Biomechanics, 9*(4), 296-303.

Ripoll, H. (1991). The understanding-acting process in sport: the relationship between the semantic and the sensorimotor visual function. *International Journal of Sport Psychology*.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. *Journal of Sport and Exercise Psychology, 35*(2), 144-155.

Schalen, L. (1980). Quantification of tracking eye movements in normal subjects. *Acta oto-laryngologica, 90*(1-6), 404-413.

Shim, J., Carlton, L. G., Chow, J. W., & Chae, W.-S. (2005). The use of anticipatory visual cues by highly skilled tennis players. *Journal of motor behavior, 37*(2), 164-175.

Starkes, J. L. (1987). Skill in field hockey: The nature of the cognitive advantage. *Journal of sport psychology, 9*(2), 146-160.

Starkes, J. L., & Ericsson, K. A. (2003). *Expert performance in sports: Advances in research on sport expertise*: Human Kinetics.

Takeuchi, T., & Inomata, K. (2009). Visual search strategies and decision making in baseball batting. *Perceptual and Motor Skills, 108*(3), 971-980E.

Tucker, R., & Collins, M. (2012). What makes champions? A review of the relative contribution of genes and training to sporting success. *Br J Sports Med, 46*(8), 555-561.

van Andel, S., Cole, M. H., & Pepping, G.-J. (2017). A systematic review on perceptual-motor calibration to changes in action capabilities. *Human Movement Science*, *51*, 59-71. doi:10.1016/j.humov.2016.11.004

Whiteside, D., Giblin, G., & Reid, M. (2014). *Redefining spatial consistency in the ball toss of the professional female tennis serve.* Paper presented at the ISBS-Conference Proceedings Archive.

Withagen, R., & Michaels, C. F. (2002). The calibration of walking transfers to crawling: Are action systems calibrated? *Ecological Psychology, 14*(4), 223-234.

Chapter 3.

To tee, or not to tee: An exploration of the relationship between practice task representativeness and performance in elite baseball hitters

Matthew McCue & Nick Wattie

Ontario Tech University

3.1 Introduction

Bryce Harper's record breaking baseball contract should remind sport scientists why their work is valuable. When an elite player receives approximately $45,000 every time they attempt one of the hardest tasks in sports, batting in baseball, the need for research that explores how that skill is developed and affected is amplified.

Major League Baseball (MLB) players, like Bryce Harper, demonstrate astounding perceptual-motor skill on a consistent basis. Rooted in the capability of striking a baseball at the professional level is perception-action coupling, the pairing of movements (i.e., actions) with the necessary contextual and perceptual information provided by an opponent and/or game situation. The dynamic nature of baseball batting and the deception that is deployed by opposing pitchers requires batters to rapidly process task relevant cues and use them to inform anticipation and decision-making processes (Gray, 2009b). This perceptual-cognitive skill (Broadbent, Causer, Williams, & Ford, 2015; Mann, Williams, Ward, & Janelle, 2007; Marteniuk, 1976) relies on an efficient visual search strategy or gaze behaviour (e.g. location and duration of gaze fixations).

Research suggests that expert hitters fixate their gaze on more task relevant areas (i.e., throwing arm and release point) and take less time to first fixate on these areas, in comparison to novices (Gegenfurtner, Lehtinen, & Säljö, 2011; Kato & Fukuda, 2002; Takeuchi & Inomata, 2009). Although there are limitations and technical considerations in eye-tracking research (see, Andersson, Nyström, & Holmqvist, 2010; Kredel, Vater, Klostermann, & Hossner, 2017, for an excellent model and systematic review) these findings are robust across high performance literature (Bard & Fleury, 1976; Hayhoe, McKinney, Chajka, & Pelz, 2012; Hubbard & Seng, 1954). This research typically focuses on the prevalence and description of expert gaze behaviour in high performance sport, yet the development of this key perceptual-cognitive skill through the practice and warm-up environment remains relatively unexplored.

Literature suggests that practice or warm-up that highly resembles competition, representative learning environments (RLEs), positively influences skill acquisition and performance (Pinder, Davids, Renshaw, & Araújo, 2011; Pinder, Renshaw, & Davids, 2009; Rosalie & Müller, 2012). The representativeness of a particular warm-up drill or practice environment is influenced by two key features: functionality and action fidelity (Krause, Farrow, Reid, Buszard, & Pinder, 2017; Pinder, Renshaw, Davids, & Kerhervé, 2011). The functionality of RLEs is the extent to which an athlete may use informational cues in practice that are also present during competition to direct decisions and movements (Pinder, Renshaw, et al., 2011). Action fidelity refers to a RLE's ability to preserve an athlete's movement pattern that is typically seen in competition (Araujo, Davids, & Passos, 2007). For example, using a ball machine in cricket practice has been shown to be low in functionality as the batter is not provided with key informational cues such as the wind-up of the bowler (Abernethy & Russell, 1984; Weissensteiner, Abernethy, Farrow, & Müller, 2008). Additionally, this drill is not high in action fidelity as it has been shown to significantly impact the spatiotemporal kinematics of cricketers during the task (Pinder et al., 2009). The inclusion of drills low in functionality and action fidelity in practice/warm-up environments have led to undesirable swing kinematics in tennis (Reid, Whiteside, & Elliott, 2010; Whiteside, Giblin, & Reid, 2014) and cricket players (Pinder et al., 2009). Furthermore, such drills have negatively impacted the extrinsic timing of volleyball players (Davids, Kingsbury, Bennett, & Handford, 2001). However, the majority of this research has a strong biomechanical focus and does not explore the potential disruption that low representative practice has on decision-making and gaze behaviour.

The ability of a professional baseball batter to overcome severe temporal and spatial constraints that are placed on them by the rapidity and movement of an approaching ball suggests they regularly participate in RLEs that groom advanced gaze behaviours and decision-making skills. Surprisingly, this is not the case, even at the professional level. For example, a quick exploration of an MLB hitting facility will undoubtedly uncover at least one practice tee. The use of a mounted ball on a stationary tee is a classic drill used by baseball players. This drill contains none of the informational cues that would be supplied by a pitcher (low functionality) and requires the batter to perform a movement pattern towards a stationary ball (low action fidelity). Although this drill may warm-up relevant muscles and tendons, it does not nurture the complex perception-action coupling needed to hit, nor does it serve as an adequate recalibration (Brand & de Oliveira, 2017) method.

The stationary tee drill, among other warm-up and/or practice tasks low in functionality or action fidelity, are ubiquitous in baseball. For instance, almost every MLB team participates in coach-thrown batting practice before each game. This task typically consists of a coach repetitively delivering one type of pitch (fastball) from a shortened distance, at a reduced velocity, to the same location. Relative to what a batter may encounter in a competition, such as multiple pitch types, high velocities, and varied locations of pitches, this drill is also low in functionality. Despite research that suggests the efficacy of contextual interference (random instead of blocked practice) in batting practice (Gray, 2017; Hall, Domingues, & Cavazos, 1994), coach-thrown batting practice is still used to warm-up batters at the highest level of competition.

The low representativeness of drills traditionally used throughout baseball and the recent discourse about MLBs warm-up routine (Kagan, 2017; Waldstein, 2012) suggests that more empirical research is needed. Thus, the purpose of this study is to explore the acute affect of common warm-up batting drills on the gaze behaviour and decision-making of elite baseball players. Specifically, the aim of this study was to explore the acute influence of three typical baseball warm-up conditions (stationary tee drill, pitching machine batting practice, and coach-thrown batting practice) on players' decision-making and gaze behaviour.

If warm-up drills that are de-coupled from competition have an acute influence on gaze behaviour, each participant should demonstrate sub-optimal visual search strategies early and progressively improve their performance as they observe more pitches. Similar findings may be assumed for their ability to predict pitch type and location. Additionally, assuming that the conditions were equally balanced, drills that are more de-coupled (i.e., stationary tee drill) will likely elicit a greater negative influence on gaze behaviour and decision-making than drills that are less de-coupled (i.e., coach-thrown batting practice).

3.2 Methodology

Study Design

A between-subjects experimental design was implemented to measure how four warm-up conditions (differing in competition representativeness) acutely influence the gaze behaviour and performance of elite baseball players. This particular design was selected as it allows the sample to be divided into four groups and does not require the participants to return for multiple trials over an extended period of time. This is optimal for analyzing elite athletes as their participation in research is typically constrained by a busy practice and game schedule. Additionally, the dynamic and complex nature of striking a baseball supports a conservative between-subjects design as a means to evade carry-over or demand effects that are noted in within-subject designs (Charness, Gneezy, & Kuhn, 2012). A pre-study questionnaire was disseminated to the participants that identified their playing experience, skill level, handedness and age. These results were used to balance and ensure a high degree of similarity between experimental groups.

Inclusion Criteria

Athletes were eligible to participate if they meet the following criteria:

- 18-40 years old, have 20/20 or corrected to 20/20 vision, and not currently experiencing discomfort or an injury that may inhibit a full baseball swing.
- Must have competed for a National College Athletic Association (NCAA), National Junior College Athletic Association (NJCAA), National Association of Intercollegiate Athletics (NAIA), Ontario University Athletics, Ontario Colleges Athletic Association, or semi-professional baseball team (e.g., Canadian American Association of Professional Baseball, Intercounty Baseball League, Northwoods League, and Western Major Baseball League). Athletes in this sample are to be classified as advanced as these leagues are reflective of national level competition or high level intercollegiate competition (Baker, Wattie, & Schorer, 2015).

Procedure

Participants were recruited and asked to fill out consent and a brief questionnaire assessing playing experience prior to arriving for the trial (Appendix C).

Pre-trial questionnaire. **Date of Birth** was requested to determine the age of each participant at the time of the study. One of three options were used to identify **handedness**: right, left, or switch. No participants that volunteered for the study happened to be switch hitters. **Playing level** was defined as tier 1 or 2 and determined from a series of questions (questions 1-3 in Appendix C) that inquired about playing experience. Players were categorized as tier 1 if they ever received an athletic scholarship from an NCAA, NJCAA, or NAIA institution or if they participated in any of the semi-professional/amateur leagues listed in the *inclusion criteria* (page 30; See also question 3 appendix C). Health concerns and previous experience in video simulations were inquired about to identify any potential confounding variables.

Warm-up protocol. Each athlete was instructed to bring any baseball equipment they would typically bring to a game and require for hitting (e.g., helmet, wood bat, batting gloves, metal cleats, and running shoes). Athletes were instructed to conduct their typical warm-up protocol prior to taking batting practice (i.e., running and stretching). Once ready, each group performed twenty practice swings (typical of a traditional warm-up in baseball) in one of four experimental conditions. Group A was instructed to warm-up completing twenty 'dry' swings with no ball involved (Group A will be the control group for the study). Group B hit a ball off a standard Tanner Tee™. This device holds a ball in a stationary position and allows athletes to repetitively swing at the same location. Once the ball was launched off the tee by a bat, another ball was placed on the top of the stand. The height and location of the ball on the tee was determined by each participant's personal preference. Group C swung at a ball delivered from a pitching machine that stood 60 feet and 6 inches from the batter (the distance from the pitcher's mound to home plate). The velocity of the pitching machine (85 miles per hour) was the average velocity the athletes see at practice as indicated in the pre-study questionnaire. Group D struck a moving ball delivered from 45 feet away by a coach certified by the Ontario Baseball Association. This coach did not have a current or previous association with any of the participants involved. This warm-up protocol took approximately one hour and fifteen minutes to complete.

Experimental trials. The video simulation took place in the Ontario Tech University Kinesiology lab. Athletes were fitted with a SensoMotoric Instruments (SMI) Mobile eye tracker, which was attached to a tablet that was secured to the athlete's back (using straps and a carrying case). This process ensured the preservation of action fidelity which improved participant immersion. The mobile eye tracker was configured using a three-point calibration on a paused image of the simulation. This ensured the precision of the gaze behaviour measurements as the mobile eye tracker was calibrated relative to the experimental task and positioning of an in-game at-bat. Video was recorded with a sampling rate of 120 Hertz.

Participants were instructed to swing or not swing at simulated pitches with the same intent seen in a game. A pitcher was projected on the screen and was scaled to appear to be 60 feet and 6 inches away, the regulation distance of a mound to home plate ("Official Baseball Rules," 2018). The batter observed twenty consecutive pitches with a break of 15 seconds between each pitch. Three different pitch types were used in the trial:

fastball, curveball and changeup. The ability of expert batters to improve performance when they are able to predict pitch information (Paull & Glencross, 1997) suggested that pitch type accuracy would be a key indicator for success. A combination to note was the athlete's ability to distinguish between fastballs and changeups as this has recently been correlated to higher on-base and base-on-ball percentages in minor league players (Müller & Fadde, 2016).

The video simulation showed the wind-up of the pitcher, release of the ball, and the ball as it travels towards the hitter. The ball flight was temporally occluded with a black screen at 333 milliseconds, 200 milliseconds, and 100 milliseconds after ball release from the pitcher's hand. These occlusion times stem from Adair's (2002) findings centered on the physics of baseball and decision-making. Immediately after the completion of a swing, the athlete was asked to verbally indicate the pitch type (fastball, curveball, and changeup) and final pitch location. This process is consistent with the finding that college baseball players are able to use 200 ms of ball flight to distinguish between fastballs and curveballs with 90% accuracy (Burroughs, 1984). A scaled strike zone segmented into four quadrants was displayed directly below the projection screen for visual reference (see Figure 1). This think aloud protocol and verbal indication of final pitch location has previously been used for cricket batters (McRobert et al., 2011). The athlete was asked to complete their swing (or their take if they chose not to swing) before indicating pitch type to preserve perception-action coupling (Farrow & Abernathy, 2003) and an immersive atmosphere that more completely replicates real-game movements and decisions.

Variables

Two phenomena that are crucial for successfully striking a baseball, decision-making and gaze behaviour, were recorded and analyzed. The main *independent* variable in this study was the **warm-up condition** that the participants completed (i.e., Groups A, B, C, and D). Two secondary *independent* variables, **playing level** (tier 1 or 2) and **handedness** (right or left), were also included in analyses to determine their potential impact on gaze behaviour and decision- making.

Decision-making. Three nominal *dependent* variables were monitored to capture decision-making: Pitch type (i.e., fastball, curveball, and change-up), Quadrant location (i.e., pitch location as it crosses the plate; see Figure 1) and Ball or Strike.

The sum of correct predictions were calculated as well and reported as total correct predictions. The apparatus used to visually demonstrate the strike zone and four quadrants was designed to represent the average strike zone seen in Major League Baseball (MLB) competition (Fast, 2001). The quadrant location and ball/strike decisions acted as secondary and tertiary indicators of successful pitch prediction.

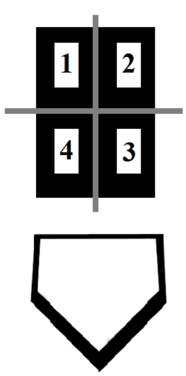

Figure 1. *Scaled strike zone that batters used to determine quadrant location*. Batters also referred to this strike zone for their ball/strike decision.

Gaze Behaviour. Literature suggests that expert athletes participating in interceptive sports use efficient and fixated visual search strategies (Bard & Fleury, 1976; Gray, 2009a; Kato & Fukuda, 2002; Shim, Carlton, Chow, & Chae, 2005). The main constituent of gaze behaviour that was monitored was fixation behaviour. The criteria for a fixation was the gaze remaining stationary within 1.5° of visual angle for a duration greater than 120 ms (Savelsbergh, Williams, Kamp, & Ward, 2002; Takeuchi & Inomata, 2009). Fixation behaviour assessment (location and duration) for all 18 pitches in the trial began 500 ms before release of the ball and continued until the ball was released.

One nominal and three ratio *dependent* variables were utilized to assess the gaze behaviour of each participant:

- Location of fixations pre-release of the pitch

  Legs, trunk/torso, head/neck, elbow/release point, and unclassified (background or task irrelevant information)

- Duration of fixations in each location
- Time to Release Point Fixation (TtRPFix) - the amount of time (in ms) before the batter initiates a fixation on the release point.
- Final fixation duration (Fix*f)* - the duration (in ms) of the last fixation the batter makes before the ball is released.

The location, duration and quantity of these fixations were the key variables and provided valuable information about how these elite hitters gleaned information about pitch type pre-release. The timing of TtRPFix indicated if any of the warm-up conditions acutely affected the batter's ability to efficiently and accurately locate the release point of the ball. Additionally, Fix*f* and TtRPFix provided insight about the quickness of identifying task relevant areas (i.e., a low TtRPFix suggests the participant located the release point promptly) and their visual focus before the ball was released.

Analyses

Decision-making. A three-way factorial ANOVA was employed to analyse **total correct predictions** (pitch type + quadrant + ball/strike) with warm-up condition, handedness, and playing level as the between-participants and occlusion segment (late, mid, and early) as the within-participant variable. A two-way factorial ANOVA was performed that specifically assessed **pitch type predictions** (correct or incorrect) with warm-up condition and handedness as the between-participants variables, and occlusion segment and pitch type (fastball, curveball, change-up) as the within-participant variables.

Gaze Behaviour. Following a similar structure to total correct predictions, the **total number of release point fixations** and **Fix*f*** were analyzed separately through the use of three-way factorial ANOVAs with warm-up condition, handedness and playing level as the between-participants variables and occlusion segment as the within-participants variable.

To properly assess TtRPFix, a more recent statistical approach was taken. This outcome variable presents difficulties for traditional analyses as it resulted in a number of missing values for each pitch where a fixation on the release point did not occur. Furthermore, an imbalance in the number of TtRPFixs between individuals was likely as it would be improbable to expect a homogenous number of fixations on the release point. For these reasons, a linear mixed model, which does not perform listwise deletion and is thus robust to missing data points (Jaeger, 2008; Krueger & Tian, 2004) was performed in lieu of a repeated measures factorial ANOVA. Warm-up condition, handedness, and playing level were entered into the model as effects with **TtRPFix** as the dependent variable.

Decision-making x Gaze Behaviour. A chi-square test of independence was performed to explore the relationship of between final fixation point (release point or other) and pitch type prediction (correct or incorrect). Additionally, a binomial logistic regression was used to determine if pitch type prediction performance (dichotomous – correct or incorrect) could be predicted by Fix*f*.

3.3 Results

Decision-making

No significant effects of warm-up condition on total correct predictions, F (3, 13) = .13, p = .94, η_p^2 = .03, or pitch type predictions, F (3, 13) = .52, p = .68, η_p^2 = .11, were observed. Analysis of <u>total correct predictions</u> revealed a main effect of occlusion, F (2, 26) = 5.43, p = .01, η_p^2 = .30, with athletes predicting more correct decisions in the early occlusion segment (see Figure 2). Additionally, tier 1 athletes made significantly more total correct predictions than tier 2 athletes, t (26) = 2.41, p = .02 (see Figure 3). Analyses of correct <u>pitch type predictions</u> demonstrated a main effect of pitch type, F (2, 26) = 30.90, p < .001, η_p^2 = .70, as well as significant interactions of pitch type x handedness, F

(2, 26) = 5.03, p = .01, η_p^2 = .28 (see Figure 4), and pitch type x occlusion, F, (4, 52) = 19.18, $p < .001$, η_p^2 =.46. Accordingly, left handed batters performed better, and batters were significantly better at predicting fastballs than other pitchers which was amplified by earlier occlusion times.

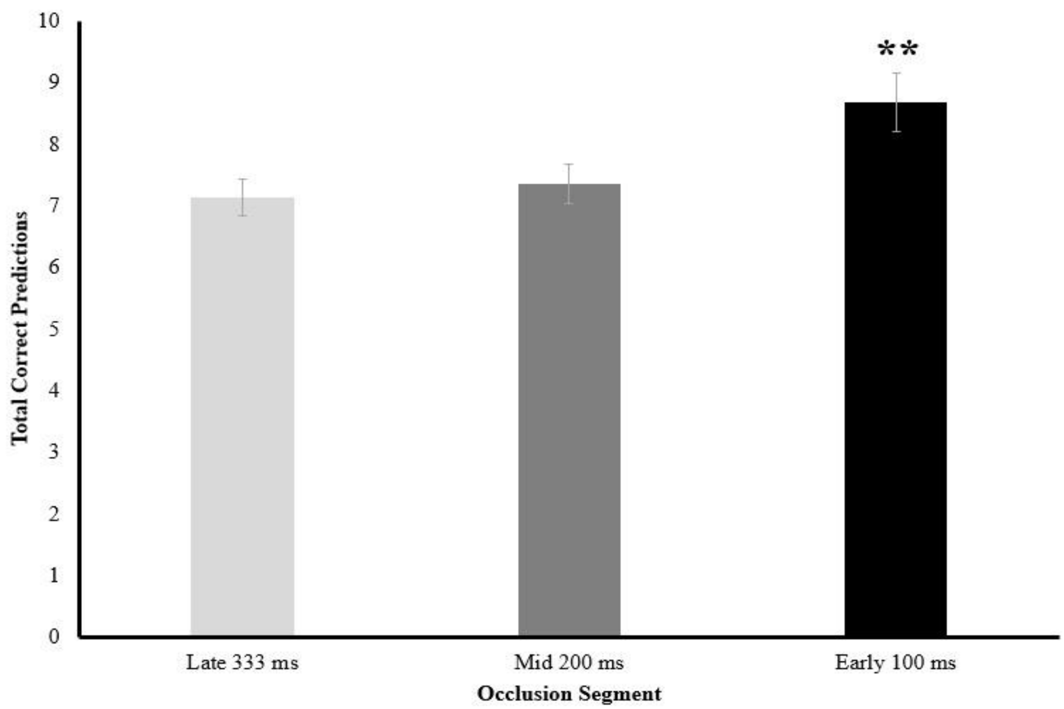

Figure 2. Total correct choices across occlusion segments. Late = 333 ms occlusion, Mid = 200 ms occlusion, Early = 100 ms occlusion. Errors bars represent standard error. ** represent significant different at $p \leq .01$.

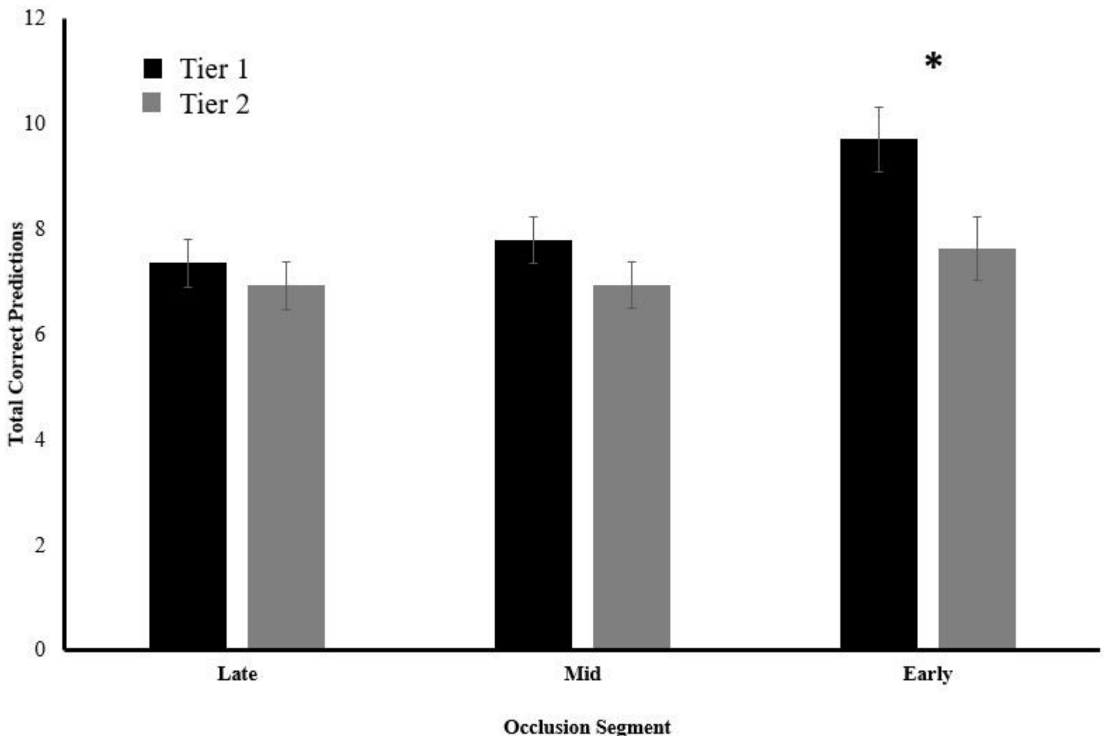

Figure 3. Total correct predictions across occlusion segments- playing level. Tier 1 players = black bars; Tier 2 players = grey bars. Late = 333 ms occlusion, Mid = 200 ms occlusion, Early = 100 ms occlusion. Errors bars represent standard error. * represents significant difference at $p < .05$.

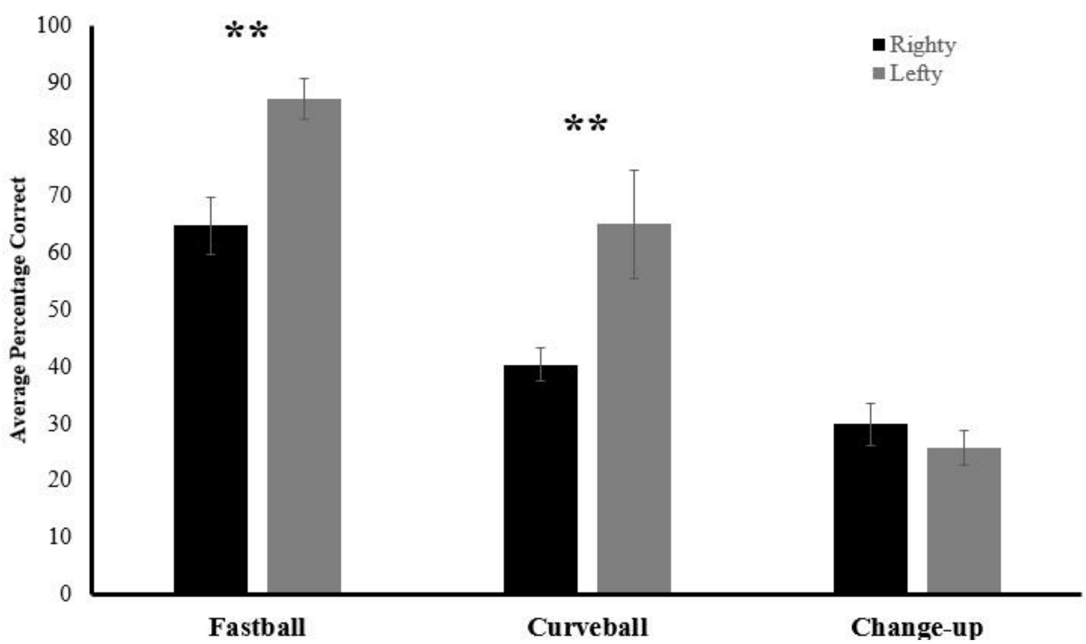

Figure 4. Percentage of correct predictions for each pitch type – handedness. Right handed batters = black bars; Left handed batters = grey bars. Error bars represent standard error. ** represents significant difference at $p < .01$.

Gaze Behaviour

Release point. The three-way factorial ANOVA with number of release point fixations as the dependent variable revealed main effects of occlusion, F (2,26) = 3.87, p = .03, η_p^2 = .23, and playing level F (1,27) = 13.06, p = .003, η_p^2 = .50 (see Figure 5). Accordingly, tier 1 players averaged more fixations on the release point than tier 2 players and all players averaged more fixations on the release point in the mid and early occlusion segments compared to the late occlusion segment. No main effects of warmup condition or handedness were observed. Assessment of the location of fixations suggest that tier 1 players also spent significantly more time fixating on the release point (M = 44.21%, SD = 2.48) than tier 2 players (M = 28.24%, SD = 2.59).

The linear mixed model ANOVA yielded similar results as a main effect of playing level on TtRPFix was observed (*df* 1; F = 16.81, p = .001) with players from tier 1 averaging a quicker TtRPFix than tier 2 players (see Figure 5). Additionally, no main effects of warmup condition or handedness were observed. However, a significant interaction of playing level x warmup condition was noted, (*df* 3; F = 3.93, p = .03).

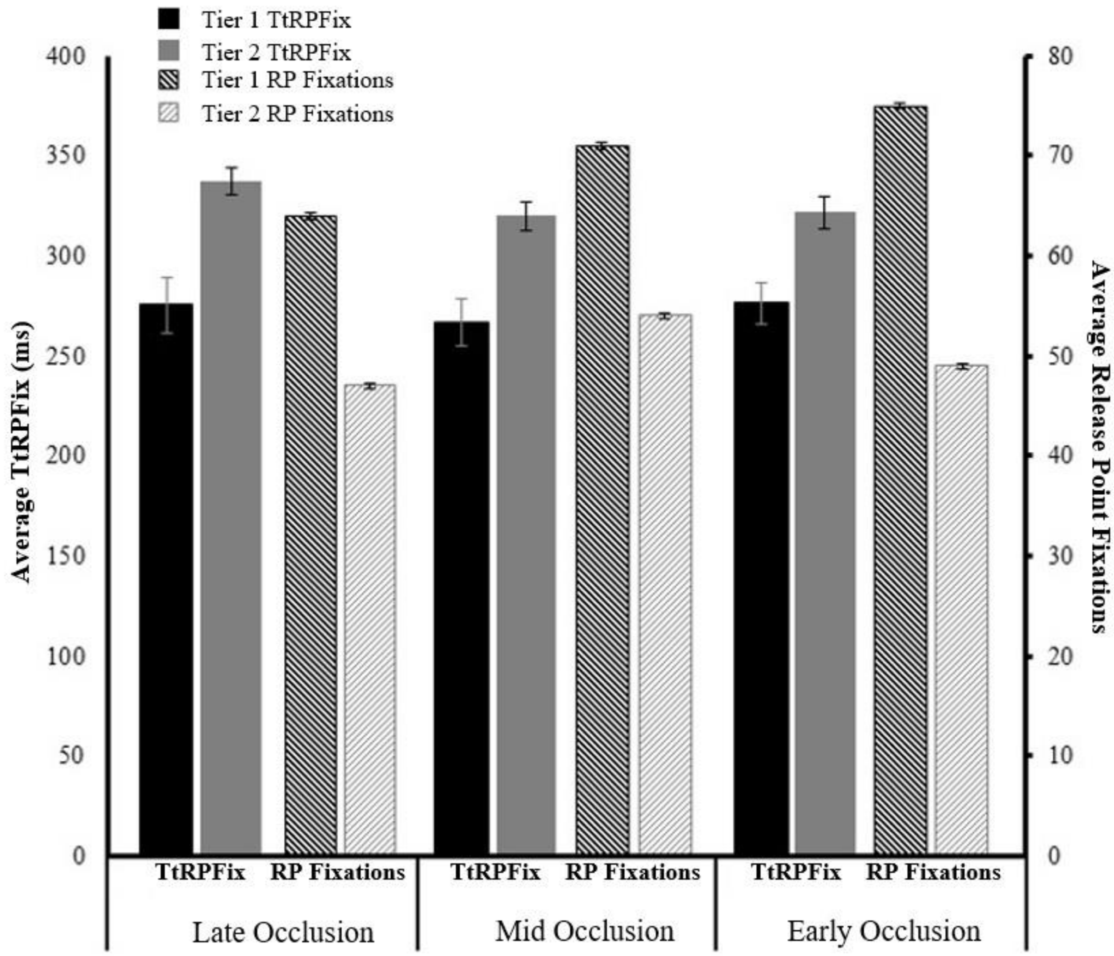

Figure 5. *Visual search strategies as they pertain to release point for tier 1 and tier 2 players*. TtRPFix = Time to Release Point Fixation, RP = Release point, Late Occlusion = 333 ms occlusion, Mid = 200 ms occlusion, Early = 100 ms occlusion. TtRPFix bars to be scaled to the left primary y axis; RP fixation bars to be scaled to right secondary y axis. Error bars represent standard error.

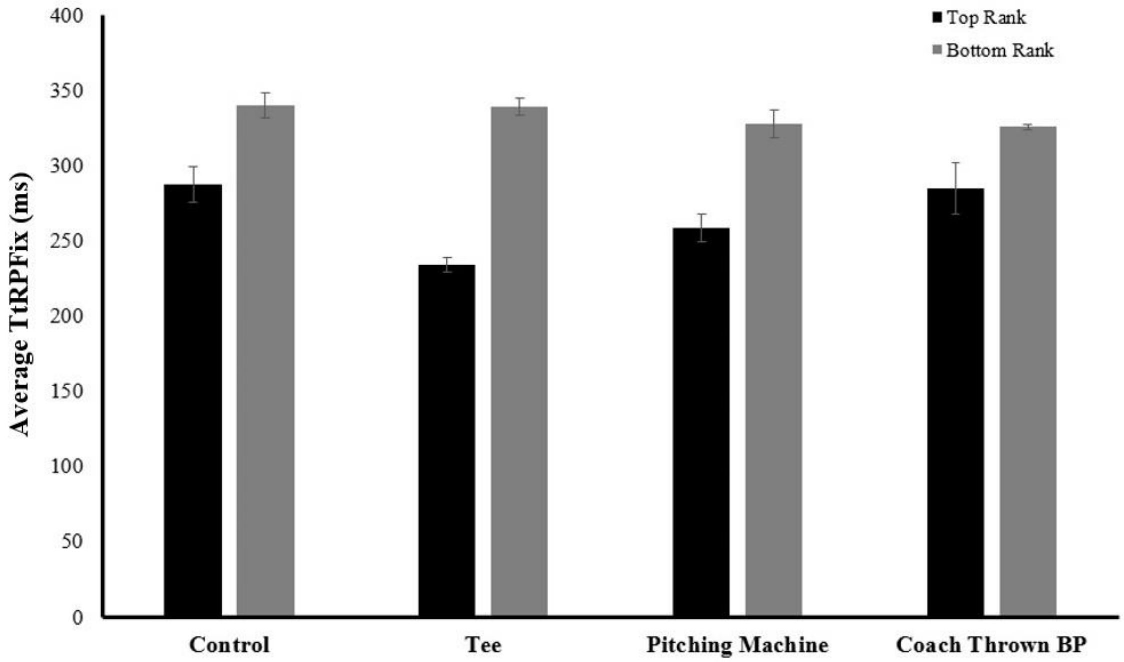

Figure 6. *Average Time to Release Point Fixation (TtRPFix) for each warm-up condition.* Black bars represent the top 3 ranked players in average TtRPFix, grey bars represent bottom 3 ranked players in average TtRPFix. Error bars represent standard error.

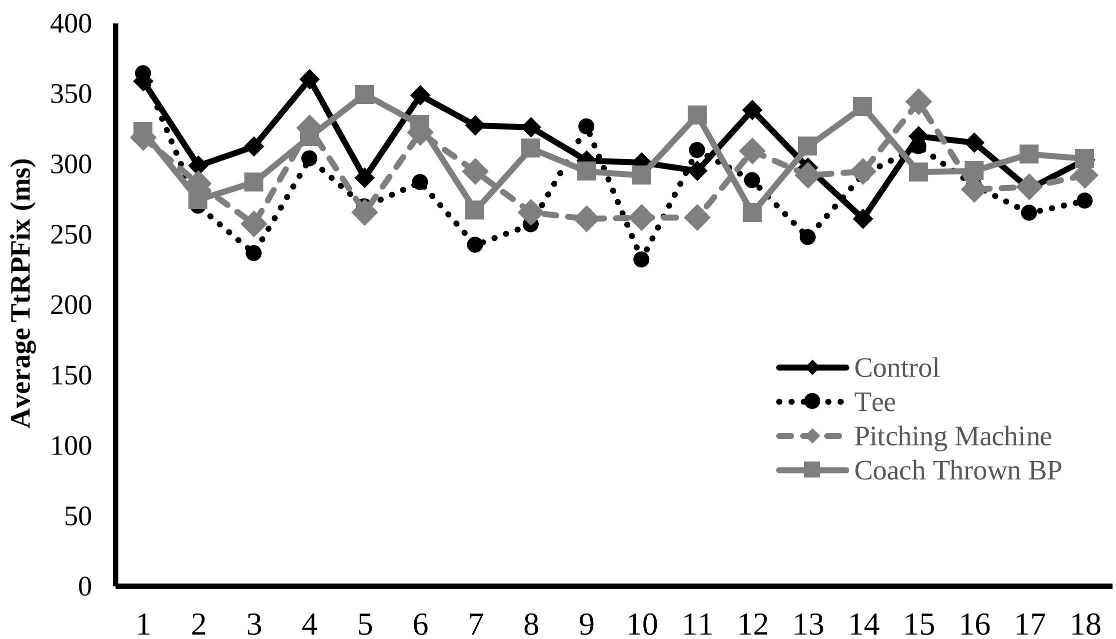

Figure 7. *Average Time to Release Point Fixation (TtRPFix) of the four warmup conditions for each pitch*. Pitches graphically represented in order they were presented to athletes.

Fixf. The duration of the final fixation before release of the ball appeared to be negatively correlated to TtRPFix, r = -.82, $p < .001$. Consequently, the three-way factorial ANOVA with Fix*f* as a dependent variable indicated a main effect of playing level, F (1,13) = 9.36, $p = .01$, $\eta_p^2 = .42$, and significant interactions of playing level x warmup condition F (3,13) = 3.83, $p = .04$, $\eta_p^2 = .47$, and handedness x warmup condition F (3,13) = 3.79, $p = .04$, $\eta_p^2 = .47$. No main effects of occlusion, warmup condition, and handedness were noted.

Although three different pitches were used in the simulation, batters did not display significantly different visual search behaviours to a specific pitch type (see Figure 8).

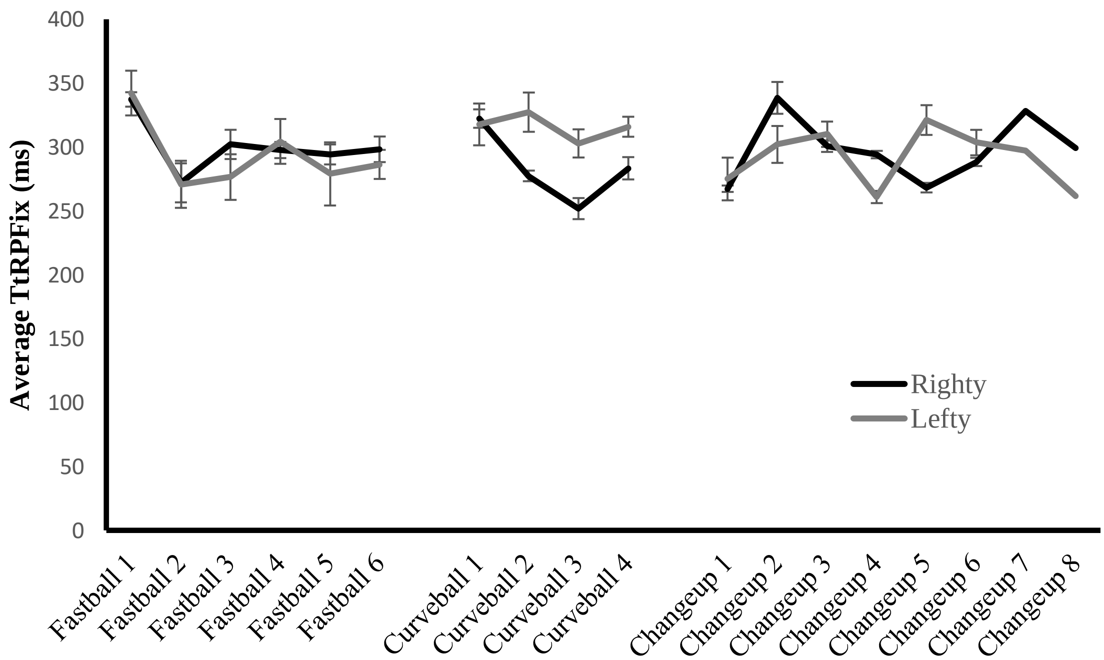

Figure 8. *Average Time to Release Point Fixation (TtRPFix) for all pitch types*. Pitches graphically represented in order of pitch type presentation (i.e., fastball 1 was the first fastball thrown but may not have been the first pitch of the simulation). Errors bars represent standard error.

Percent viewing time. Batters in the control condition spent significantly less time fixating on the release point (*M* = 31.10%, *SD* = 10.22) than players from the other three conditions (see Figure 9). Tier 1 players spent significantly more time fixating on the release point (*M* = 48.05%, *SD* ± 9.04) than tier 2 players (*M* = 36.44%, *SD* ± 10.34; see Figure 10).

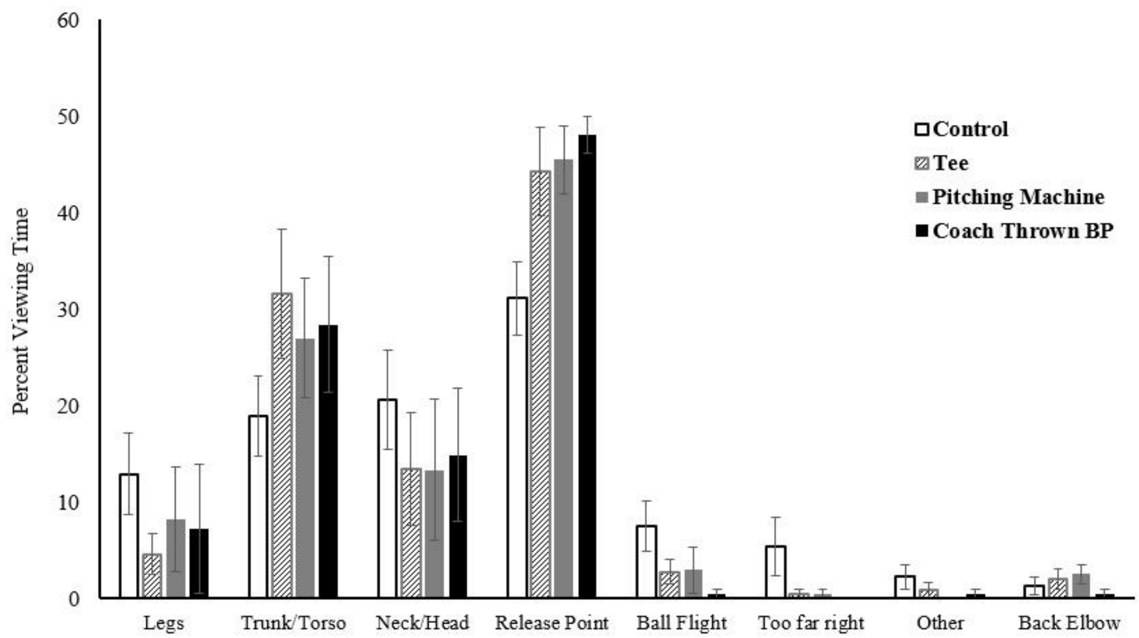

Figure 9. *Percent viewing time for each warm-up condition.* Viewing time represented as an average. Errors bars represent standard error.

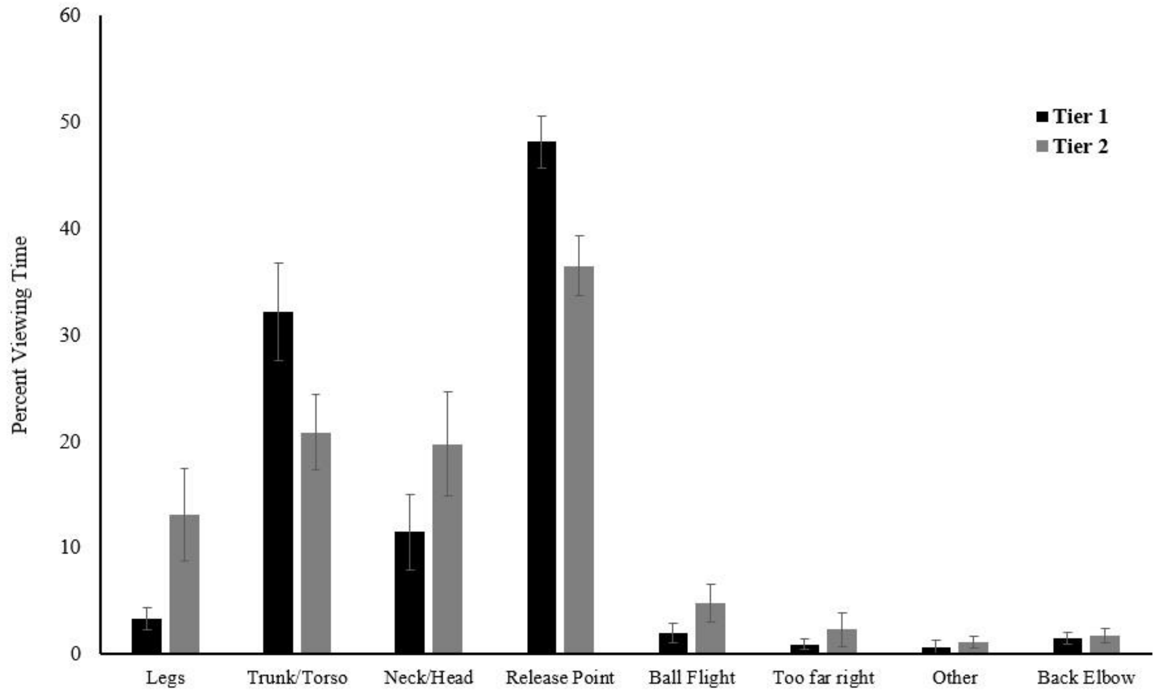

Figure 10. *Percent viewing time for each playing level*. Viewing time represented as an average. Errors bars represent standard error.

Decision-making x Gaze Behaviour

The relation between final fixation location (release point or other) and correct pitch type identification was significant, χ^2 (1) = 78.67, p <.001, ϕ_c = .395. Batters made significantly more correct pitch type predictions when they were able to fixate on release point directly before the release of the ball. The logistic regression model used to ascertain the effect of Fix*f* on the ability to predict pitch type was statistically significant (χ^2 (1) = 6.85, p = .04, OR .99, 95% CI: .995-1.00), although only marginally and with negligible effect size.

3.4 Discussion

The goal of the current study was to assess the influence that unrepresentative batting drills may have on the decision-making and gaze behaviour of elite baseball players. An additional focus was to explore how variables such as playing experience, handedness, occlusion time, and pitch type may affect these results. Consistent with previous research on skilled baseball hitters (Kato & Fukuda, 2002; Takeuchi & Inomata, 2009), the location and duration of the batters' fixations appeared to be a significant indicator for decision-making success and a predictor of playing experience. However, the lack of a warm-up condition effect did not align with our hypothesis, or literature that suggests de-coupled practice may negatively affect batting performance (Davids et al., 2001; Pinder et al., 2009; Reid et al., 2010; Whiteside et al., 2014). While this was an unexpected result, a number of potential explanations exist. One possible interpretation is that the advanced skill of this sample allowed the participants to overcome the acute influence that may be inflicted by these de-coupled drills. Although previous research suggests that de-coupled practice disrupts the extrinsic timing and spatiotemporal kinematics of skilled performers, perhaps the disruption on other measures of expert performance such as gaze behaviour and decision-making are mitigated by skill. This could be further explored in a novice population.

The lack of a warm-up effect may also be explained by skill in recalibration. Brand & de Oliveira (2017) suggest that recalibration may only occur after a disturbance has been applied to either perception or action resulting in a disruption to perception-action coupling. In this case, it is possible that all of the traditional drills used in the study disrupt the perception-action coupling of the batters. Lack of visual cues provided by a pitching machine, absent contextual interference in coach-thrown batting practice, and not pairing the rotation of the head with the velocity of an approaching pitch in the stationary tee drill all function as potential disturbances to the link between perception and action. Despite the disturbances, the batters may have overcome any influence on decision-making and gaze behaviour as they have endured this recalibration process their entire career. Indeed, it is plausible that the frequent exposure to de-coupled batting drills has led to skill in recalibration.

Finally, it must be considered that these drills simply do not acutely impact the decision-making or gaze behaviour of elite baseball players. Although this study was novel in its assessment of the acute effects of unrepresentative practice on gaze behaviour and decision-making, no such evidence for or against this relationship in interceptive sport was found in the literature. Future studies are needed to further explore this relationship in youth sport and other domains. Indeed, some of the results from the current study suggest the importance of continued research on the acute influence of warm-up and practice drills.

Decision-making

The goal with decision-making analysis was to determine what could potentially affect the participants' abilities to make correct predictions about the characteristics of an approaching pitch. Pitch type predictions were a point of emphasis as the ability to discern a fastball from a curveball or change-up significantly impacts the chances of successfully striking an approaching pitch (Burroughs, 1984; Müller & Fadde, 2016). This was supported in this study as all players predicted fastballs more accurately than curveballs and changeups (Figure 4). The main effect of pitch type and interaction noted between pitch type and handedness likely resulted from the left-handed batters' ability to predict fastballs with 87% accuracy and curveballs with 65% accuracy. This proficiency at predicting pitch types supports the notion that batters facing opposite handed pitchers (i.e., left-handed batter vs right-handed pitcher) have an advantage over like-handed batters (Goldstein & Young, 1996; Lindsey, 1959).

A main effect of occlusion time (Figure 2, 3) was noted as athletes made more total correct predictions in the last segment of pitches (early occlusion) in comparison to the first segment (late occlusion). This suggests that although the trial was getting progressively harder (i.e., less ball flight information) the participants were able to make better use of contextual information to inform decision-making. These findings are similar to McPherson (1993) which suggested that batters may analyze an opponents' characteristics and use this contextual information to predict subsequent pitches. However, athletes' decision-making should have been less accurate in the early occlusion times; this result may have been due to the study design (see Limitations section below).

Gaze Behaviour

While the results of decision-making largely focused on the participants' competency at extracting key pitch information during ball flight, gaze behaviour analyses demonstrated the batters' visual tendencies pre-release of the ball. For instance, type of pitch was a main effect in correct pitch type predictions, yet it did not appear to significantly impact the visual search behaviours of the batters (Figure 8). This suggests that batters were relying on ball fight information, instead of pre-release cues demonstrated by the pitcher, to predict the type and final location of an approaching pitch. However, future research should attempt to assess this further as a hitter's ability to determine a pitcher's grip at the point of release has been widely debated (Sarris, 2016).

Gaze behaviour results further supported the athletes' use of contextual information as all players increased their number of release point fixations as the trial progressed (Figure 5). Similarly, McRobert et al. (2011) noted that expert cricket hitters, when consistently facing the same bowler, were able to adjust their visual search strategy to anticipate the natural progression of the bowler's delivery. Consistent with research on perceptual-cognitive and expertise effects (Broadbent et al., 2015; Mann et al., 2007), there appeared to be skill-related differences in this ability. When comparing tier 1 and tier 2 players, the distinction was apparent as tier 1 players totaled a higher number of release point fixations (Figure 5) and spent a higher percentage of their time fixating on the release point (Figure 10). Although all participants in this sample were elite, this suggests their classification by tier was appropriate, but that it may also be necessary to further study the influence of de-coupled practices using expertise approaches (i.e., expert-novice or skill-group paradigms: Abernethy, Gill, Parks, & Packer, 2001; Farrow & Abernethy, 2003).

With respect to TtRPFix and Fix*f*, results suggest these metrics may be useful tools in talent identification and development. Both measures demonstrated main effects of playing level, with tier 1 athletes fixating on the release point earlier (i.e., shorter TtRPFix) and for a longer amount of time. The negative correlation between Fix*f* and TtRPFix is logical as a fixation with earlier onset leaves more time for that fixation to persist. However, researchers and other professionals interested in talent identification via Fix*f* should exercise caution as the location of the final fixation is exceedingly important.

For instance, there was a significant relationship between final fixation location (release point or other) and correct pitch type identification. If one were to state that a longer Fix*f* was better in general, an athlete who demonstrates a long Fix*f* in a task irrelevant area (i.e., legs) could be selected for which is obviously not optimal. This could also be an area to target in perceptual-cognitive skill interventions where participants attempt to fixate on the release point, and other task relevant areas, earlier and for longer durations.

While no main effect of warm-up condition was observed, significant interactions between warm-up condition and playing level were noted when TtRPFix and Fix*f* were used as dependent variables. This appeared to be influenced by the surprising proficiency of the tier 1 players that warmed up in the tee condition (Figure 6) as three of these players ranked in the top four of the entire sample for TtRPFix. Consequently, these three players also ranked as the top three players for Fix*f*. Indeed it is possible that the visual search abilities of the elite players in this group were a confounding variable. It should be noted that these three players progressively decreased their TtRPFix and increased their Fix*f* in each occlusion segment (similar to the rest of the sample). Also of note, players who warmed-up in the coach-thrown and pitching machine batting practice groups averaged lower TtRPFixs on the first pitch of the simulation than those in the tee and control groups (see Figure 7). Namely, participants who completed the tasks more representative of competition were able to fixate on the release point in the first pitch of the trial quicker than those who completed the less representative tasks. This observation was not statistically significant, but it does support the original hypothesis of an acute de-coupled practice effect. Similarly, when assessing the percent viewing time for all warm-up conditions (Figure 9), the control condition spent less time fixating on task relevant areas, such as release point and trunk/torso, and more time fixating on task irrelevant areas. Considering that the control condition did not significantly differ in other metrics of gaze behaviour or decision-making, this suggests that their visual search strategy of the pitcher's delivery was disrupted by a lack of warm-up.

3.5 Limitations

Future research should aim to address some limitations to this study. First, no general, haptic, or audio feedback was provided to the athletes after they completed a swing. Participants may have used feedback, such as vibration of the bat (Carello, Thuot, Anderson, & Turvey, 1999) or the sound of bat-ball contact (Gray, 2009a), to determine the veracity of their predictions. One potential resolution moving forward may be to provide feedback about the accuracy of predictions to the batters immediately after a prediction is made. Alternatively, researchers could design simulations that do contain haptic feedback (for research designs that include haptic feedback, see: Gray, 2002; Gray, 2009a, 2017).

This study also did not include situational information nor did it present pitches in a sequence that could be predicted. This is not fully representative of a game situation as a batter's swing in competition is significantly influenced by previous pitches and the situation (Gray, 2002). For instance, a batter in a favourable count, such as 3 balls and no strikes (3-0), has a decision-making advantage as the pitcher must throw a strike to avoid walking the batter. In this situation, the hitter would likely predict that the pitcher is going to throw the pitch they can control the best (typically a fastball). The use of situational probabilities has been demonstrated empirically in experienced baseball (Gray & Cañal-Bruland, 2018) and tennis (Farrow & Reid, 2012) players. However, this would be difficult to implement in a laboratory setting as participants would likely differ in their approach to certain situations (i.e., some batters may prefer to hit change-ups instead of curveballs). The randomness of the pitch sequence used in this study also attempted to mitigate potential order effects.

The use of a projection screen, instead of a live pitcher or virtual environment, is another limitation to this study. While literature was consulted and measurements were diligently made to strengthen ecological validity, batters still may not have been immersed to the degree they would be in the field. To aid with immersion, batters stood in their normal stance relative to a plate that was placed on the ground. Future research on baseball batters should consult Gray (2002, 2009a, 2017) if more immersive atmospheres or technologically advanced study designs are desired.

Another notable limitation of this study was that no baseline values were collected for each participant. Theoretically, it would be ideal to have this information to compare how the performance data may have differed after completing a warm-up drill. However, this sample consisted of high performance athletes with intensive schedules, which posed a significant obstacle for the collection of just one trial. Additionally, the design of this study was tailored to observe an acute effect, which would have been difficult to assess if batters were previously exposed to the same pitcher in a baseline trial. This added contextual information and familiarity with the simulation could have served as confounding variables.

3.6 Conclusion

This study sought to explore the acute influence that unrepresentative practice/warm-up drills may have on the decision-making and gaze behaviour of elite baseball players. Although de-coupled practice has led to undesirable movement patterns in previous research (Pinder et al., 2009; Shim et al., 2005; Whiteside et al., 2014), no statistically significant warm-up condition effects were noted in this study. However, the athletes' familiarity with these unrepresentative tasks and resulting skill in recalibration may explain this finding. This was demonstrated by the quicker release point fixations for the participants who completed more representative tasks followed by a regression to the mean for all warm-up conditions. Results also support expertise research of perceptual-cognitive skill in high performance batters (Kato & Fukuda, 2002; McRobert, Ward, Eccles, & Williams, 2011; Takeuchi & Inomata, 2009) as more experienced participants employed significantly different decision-making and gaze behaviour abilities than lesser experienced participants. Future research should explore the influence that unrepresentative practice may have on the decision-making and gaze behaviour of more novice athletes to learn more about the development of these key perceptual-cognitive skills.

3.7 References

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception, 30*(2), 233-252.

Abernethy, B., & Russell, D. (1984). Advance cue utilisation by skilled cricket batsmen. *Australian Journal of Science and Medicine in sport, 16*(2), 2-10.

Andersson, R., Nyström, M., & Holmqvist, K. (2010). Sampling frequency and eye-tracking measures: how speed affects durations, latencies, and more. *Journal of Eye Movement Research, 3*(3), 6.

Araujo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: Comment on. *Ecological Psychology, 19*(1), 69-78.

Baker, J., Wattie, N., & Schorer, J. (2015). A taxonomy for researchers in skill acquisition and expertise. In *Routledge handbook of sport expertise* (pp. 145-155).

Bard, C., & Fleury, M. (1976). Analysis of visual search activity during sport problem situations. *Journal of Human Movement Studies, 3*(2), 214-222.

Brand, M. T., & de Oliveira, R. F. (2017). Recalibration in functional perceptual-motor tasks: A systematic review. *Human Movement Science, 56*, 54-70.

Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. R. (2015). Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *European journal of sport science, 15*(4), 322-331.

Burroughs, W. A. (1984). Visual simulation training of baseball batters. *International Journal of Sport Psychology*.

Carello, C., Thuot, S., Anderson, K. L., & Turvey, M. (1999). Perceiving the sweet spot. *Perception, 28*(3), 307-320.

Charness, G., Gneezy, U., & Kuhn, M. A. (2012). Experimental methods: Between-subject and within-subject design. *Journal of Economic Behavior & Organization, 81*(1), 1-8.

Davids, K., Kingsbury, D., Bennett, S., & Handford, C. (2001). Information-movement coupling: Implications for the organization of research and practice during acquisition of self-paced extrinsic timing skills. *Journal of Sports Sciences, 19*(2), 117-127.

Farrow, D., & Abernethy, B. (2003). Do expertise and the degree of perception—action coupling affect natural anticipatory performance? *Perception, 32*(9), 1127-1139.

Farrow, D., & Reid, M. (2012). The contribution of situational probability information to anticipatory skill. *Journal of Science and Medicine in Sport, 15*(4), 368-373.

Fast, M. (2001). Spinning Yarn: The Real Strike Zone, Part 2. Retrieved from https://www.baseballprospectus.com/news/article/14098/spinning-yarn-the-real-strike-zone-part-2/

Gegenfurtner, A., Lehtinen, E., & Säljö, R. (2011). Expertise differences in the comprehension of visualizations: A meta-analysis of eye-tracking research in professional domains. *Educational Psychology Review, 23*(4), 523-552.

Goldstein, S. R., & Young, C. A. (1996). " Evolutionary" stable strategy of handedness in major league baseball. *Journal of Comparative Psychology, 110*(2), 164.

Gray, R. (2002). Behavior of college baseball players in a virtual batting task. *Journal of Experimental Psychology: Human Perception and Performance*, *28*(5), 1131.

Gray, R. (2009a). How do batters use visual, auditory, and tactile information about the success of a baseball swing? *Research Quarterly for Exercise and Sport, 80*(3), 491-501.

Gray, R. (2009b). A model of motor inhibition for a complex skill: Baseball batting. *Journal of Experimental Psychology: Applied*, *15*(2), 91.

Gray, R. (2017). Transfer of Training from Virtual to Real Baseball Batting. *Frontiers in Psychology*, *8*(2183). doi:10.3389/fpsyg.2017.02183

Gray, R., & Cañal-Bruland, R. (2018). Integrating visual trajectory and probabilistic information in baseball batting. *Psychology of Sport and Exercise, 36*, 123-131.

Hall, K. G., Domingues, D. A., & Cavazos, R. (1994). Contextual interference effects with skilled baseball players. *Perceptual and Motor Skills, 78*(3), 835-841.

Hayhoe, M. M., McKinney, T., Chajka, K., & Pelz, J. B. (2012). Predictive eye movements in natural vision. *Experimental brain research, 217*(1), 125-136.

Hubbard, A. W., & Seng, C. N. (1954). Visual movements of batters. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *25*(1), 42-57.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of memory and language*, *59*(4), 434-446.

Kagan, D. (2017). The Physics of Batting Practice. *The Hardball Times*. Retrieved from https://tht.fangraphs.com/the-physics-of-batting-practice/

Kato, T., & Fukuda, T. (2002). Visual search strategies of baseball batters: eye movements during the preparatory phase of batting. *Perceptual and Motor Skills, 94*(2), 380-386.

Krause, L., Farrow, D., Reid, M., Buszard, T., & Pinder, R. (2017). Helping coaches apply the principles of representative learning design: validation of a tennis specific practice assessment tool. *Journal of Sports Sciences*, 1-10.

Kredel, R., Vater, C., Klostermann, A., & Hossner, E.-J. (2017). Eye-Tracking Technology and the Dynamics of Natural Gaze Behavior in Sports: A Systematic Review of 40 Years of Research. *Frontiers in Psychology, 8*(1845). doi:10.3389/fpsyg.2017.01845

Krueger, C., & Tian, L. (2004). A comparison of the general linear mixed model and repeated measures ANOVA using a dataset with multiple missing data points. *Biological research for nursing, 6*(2), 151-157.

Lindsey, G. R. (1959). Statistical Data Useful for the Operation of a Baseball Team. *Operations Research, 7*(2), 197-207.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology, 29*(4), 457-478.

Marteniuk, R. G. (1976). *Information processing in motor skills*: Holt, Rinehart and Winston.

McRobert, A. P., Ward, P., Eccles, D. W., & Williams, A. M. (2011). The effect of manipulating context-specific information on perceptual–cognitive processes during a simulated anticipation task. *British Journal of Psychology, 102*(3), 519-534.

Müller, S., & Fadde, P. J. (2016). The relationship between visual anticipation and baseball batting game statistics. *Journal of Applied Sport Psychology, 28*(1), 49-61.

Official Baseball Rules 184 (2018).

Paull, G., & Glencross, D. (1997). Expert perception and decision making in baseball. *International Journal of Sport Psychology*.

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology, 33*(1), 146-155.

Pinder, R. A., Renshaw, I., & Davids, K. (2009). Information–movement coupling in developing cricketers under changing ecological practice constraints. *Human Movement Science, 28*(4), 468-479.

Pinder, R. A., Renshaw, I., Davids, K., & Kerhervé, H. (2011). Principles for the use of ball projection machines in elite and developmental sport programmes. *Sports Medicine, 41*(10), 793-800.

Reid, M., Whiteside, D., & Elliott, B. (2010). Effect of skill decomposition on racket and ball kinematics of the elite junior tennis serve. *Sports Biomechanics, 9*(4), 296-303.

Rosalie, S. M., & Müller, S. (2012). A model for the transfer of perceptual-motor skill learning in human behaviors. *Research Quarterly for Exercise and Sport, 83*(3), 413-421.

Sarris, E. (2016). What Can Hitters Actually See Out of A Pitcher's Hand? Retrieved from https://blogs.fangraphs.com/what-can-hitters-actually-see-out-of-a-pitchers-hand/

Savelsbergh, G. J., Williams, A. M., Kamp, J. V. D., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of Sports Sciences*, *20*(3), 279-287.

Shim, J., Carlton, L. G., Chow, J. W., & Chae, W.-S. (2005). The use of anticipatory visual cues by highly skilled tennis players. *Journal of motor behavior*, *37*(2), 164-175.

Takeuchi, T., & Inomata, K. (2009). Visual search strategies and decision making in baseball batting. *Perceptual and Motor Skills*, *108*(3), 971-980E.

Waldstein, D. (2012). Cherished Tradition or a Colossal Waste of Time? *The New York Times*. Retrieved from https://www.nytimes.com/2012/08/17/sports/baseball/batting-practice-cherished-tradition-or-colossal-waste-of-time.html?module=inline

Weissensteiner, J., Abernethy, B., Farrow, D., & Müller, S. (2008). The development of anticipation: A cross-sectional examination of the practice experiences contributing to skill in cricket batting. *Journal of Sport and Exercise Psychology*, *30*(6), 663-684.

Whiteside, D., Giblin, G., & Reid, M. (2014). *Redefining spatial consistency in the ball toss of the professional female tennis serve.* Paper presented at the ISBS-Conference Proceedings Archive.

Chapter 4. Thesis Discussion

4.1 Summary

The development of elite level performance, and factors that may affect performance at this stage, have been a focus of research for decades (Baker, Wattie, & Schorer, 2015; Chase & Simon, 1973; De Groot, 1965; Ericsson, Krampe, & Tesch-Römer, 1993). It has been noted that performers traverse the expertise developmental pathway with varying constraints and that all performers must invariably engage in practice to achieve an elite status.

The commonality of practice in the development of expert performance prompted researchers to assess how its design and structure may impact learning and performance. One theoretical paradigm suggests that tasks more representative of competition have positive influences (Rosalie & Müller, 2012) and unrepresentative tasks have negative influences on performance (Pinder, Renshaw, & Davids, 2009; Shim, Carlton, Chow, & Chae, 2005). Furthermore, the relationship between practice design and performance may be amplified if the performer routinely engages in activities that requires the calibration of action capabilities to appropriate perceptual information (Brand & de Oliveira, 2017; van Andel, Cole, & Pepping, 2017; Withagen & Michaels, 2002). If an activity perturbs the perceptual-motor system, such as an unrepresentative task, then a recalibration process is required before accuracy in performing skilled actions can be ensured. Indeed, these findings were the basis of the rationale for the current study. To my knowledge, this study was novel in its exploration of the relationship between representative learning design and gaze behaviour. It was hypothesized that unrepresentative tasks would have an acute influence on the perceptual-cognitive skills of elite baseball players.

Twenty-eight elite baseball batters were recruited as they routinely perform one of the most challenging perceptual-cognitive-motor tasks in interceptive sports. Participants engaged in traditional baseball warm-up activities, differing in degrees of unrepresentativeness from competition. Decision-making was assessed through the accuracy of predictions (i.e., type and location of pitch, and strike vs. ball) and metrics of gaze behaviour were obtained via mobile eye tracker. Results suggested that occlusion time, playing level, and handedness all significantly affected decision-making, but no statistically significant warm-up condition effects were observed. There were descriptive, but not statistically significant, indications of an acute warm-up condition effect, and significant occlusion time and playing level effects were noted in gaze behaviour analyses. The quickness of fixation on the release point (TtRPFix) and duration of the last fixation before release of the ball (Fix*f*) also could be useful tools in talent identification.

Although no significant warm-up effect was noted in this study, researchers and stakeholders in skill acquisition and athlete development fields should still consider the representativeness of a task when attempting to optimize performance and learning. Unrepresentative tasks have been shown to negatively affect perception-action coupling in both skilled (Davids & Jones, 1999; Shim et al., 2005) and developing (Davids, Kingsbury, Bennett, & Handford, 2001; Pinder et al., 2009) athletes. Furthermore, it is plausible that the acute effect of de-coupled warm-up was confounded by the advanced skill of this sample. All participants possessed at least collegiate level playing experience, and perhaps more importantly, have endured prolonged exposure to unrepresentative practice activities throughout their careers. During introduction to the sport, baseball requires youth athletes to hit off a stationary tee or a pitching machine before progressing towards facing a pitcher. These drills, in combination with coach-thrown batting practice, are then used at every level of competition, including elite and professional. Moreover, as athletes develop they will have routinely had to warm-up/practice using unrepresentative tasks prior to performing representative tasks in competition. This familiarity with unrepresentative tasks, and moving from unrepresentative to representative tasks, may have impacted results as the participants likely developed a skill in recalibration at switching between tasks. Future research may benefit from exploring this hypothesis in elite level athletes. Additionally, further research should explore the influence of unrepresentative tasks on the perceptual-cognitive skills of more novice and youth athletes. These research ventures would provide valuable insight on the development of perceptual-cognitive skills and may suggest significant implications for talent identification, skill acquisition, and athlete development fields.

4.2 Future Research

While the current study explored a novel concept in high performance baseball players, future research should address some notable limitations and expand on the generalizability of the findings. For instance, it is stated throughout this thesis that the drills used in the study differed in degrees of de-coupling from competition. Future research could attempt to quantify the difference in representativeness through a tool such as the Representative Practice Assessment Tool (RPAT). The RPAT was designed by Krause and colleagues (2017) to assess and quantify the action fidelity and functionality of practice tasks typically used in tennis. This allows coaches and researchers to appraise the efficacy of their practice designs and as such, increases the potential for skill transfer to competition. A study that modifies the RPAT for baseball would be dual purposed as coaches would acquire access to this useful tool, and researchers may use it to quantify the representativeness of tasks used in the typical practice environment. If this information was available, researchers could map (or regress) the RPAT score onto dependent variables, which would provide a more accurate representation of the relationship between practice activities and dependent variables that represent performance. In fact, modifying the RPAT for all interceptive sports may be conducive for any person that is attempting to optimize learning environments.

There is also a need for more longitudinal studies in this area. To address the lack of baseline measurements noted in this study, it may be beneficial to implement an intervention study over time. For example, Gray (2017) constructed a 6 week training intervention study where performance in virtual, on-field practice, and league competition environments was assessed. This study also tracked the athletes' highest level of competition achieved for five years after the intervention. Study designs of this nature, while costly, allow the researcher to more accurately assess the near and far transfer of the training intervention. Although the schedules of these high performance populations pose as an obstacle, a measurement of how each unrepresentative task affects an individuals' decision-making and gaze behaviour would be extremely insightful. This research would likely require a counterbalance design where each athlete must return for five trials over a period of time. The participant could complete a baseline measure first, and then return four subsequent times to complete the simulation after each warm-up condition (order of warm-up condition could be randomly assigned). Such a design would allow researchers to assess how each warm-up condition may affect an individual. This would require robust partnerships between a sports team or high performance athletes and the research team.

The hypothesis that the sample used in this study could have had a skill in recalibration at switching between tasks may also be explored with further research. To do so, the affect that unrepresentative tasks have on performance could be compared between expert and more novice athletes. A skill in recalibration may be noted if the experts are less affected by the unrepresentative tasks or if novices get better at recalibration over time. This study design would also be insightful for athlete development and skill acquisition literature as this relationship has not been explored in more novice populations. Of course, these designs may be applied to any domain that requires the scaling of a skilled action to perceptual information, such as tennis, softball and cricket.

4.3 Implications

Direct benefits

This information was likely novel for the athletes as mobile eye trackers are typically expensive and not abundant in the sport community. Thus, participants that may have been financially constrained were given access to advanced technology. This visual data may be used to gather an understanding of their own visual process whilst hitting, which they can use to improve their own performance. Developing baseball players are encouraged to analyze the gaze behaviour results presented in chapter 3 as they delineate what elite players are looking at prior to the release of a pitch. Findings from this research suggest that players were most successful in their predictions of pitches when they fixated on the release point earlier, more frequently, and for a longer duration.

Results from this study also add to the growing body of literature focused on representative learning design and perception-action coupling in sport. Coaches, scouts and players in the baseball community may access our results and use them as a tool to help design an optimal practice environment. Hopefully, this information will contribute to coach professional development and may inform pedagogical approaches.

Benefits to sport research

This study has potential implications for the youth sport community as well. Specifically, novice baseball players learn how to hit off of a tee as an introduction to the sport. There are competitive tee-ball teams for those that truly excel at this skill. As athletes age, they progress to leagues where hitting off of a pitching machine replaces the tee. According to the official rules of Baseball Canada, batters will not face pitches delivered from an opposing pitcher until age 11 ("Official Rules of Baseball - Canadian Content," 2018). The drills that we use at a grassroots level to build the foundation of a very intricate skill are low in representativeness. Moreover, selection and de-selection decisions are being made on a youth athlete's competency in tasks that do not represent competition in later years. Although these drills low in representativeness did not appear to significantly influence the sensorimotor network of elite athletes, it is still possible that the impact is far greater on developing youth athletes.

Of course, these results may also be applied to any sport that requires the scaling of a skilled action to perceptual information, such as tennis, softball and cricket. The similar movement pattern and necessary tracking requirements suggests that results from this study may be applied and explored within each discipline. Coaches in these sports integrate a number of drills that vary in representativeness to the warm-up or practice routine. The novel design of our study has provided the research community with opportunities to expand in to other interceptive sports or explore different aged cohorts.

Beyond sport

This research may also be applied to other professional domains that require fine motor skills to be developed through the optimal training environment. Literature suggests that differences in expert and novice gaze behaviour have been observed in the medical (Eivazi et al., 2012; Law, Atkins, Kirkpatrick, & Lomax, 2004; O'Neill et al., 2011) and aviation (Kasarskis, Stehwien, Hickox, Aretz, & Wickens, 2001) fields. Numerous studies have focused on gaze behaviour disparities relative to expertise in these domains, yet similarities may be drawn to elite sport as limited research has focused on the potential influence training methods may have on gaze behaviour. Gaze training appears to be a fruitful pedagogical method in these domains as it has benefitted the surgical knot tying (Causer, Harvey, Snelgrove, Arsenault, & Vickers, 2014) and technical laparoscopic (Wilson et al., 2011) skills of medical trainees. Perhaps future research may explore task representativeness as it pertains to learning environments, and gaze behaviour in the medical, aviation and military fields.

4.4 Conclusion

In summary, the gaze behaviour and decision-making abilities of elite baseball players were studied after they completed practice/warm-up tasks that were unrepresentative of competition. It was hypothesized that drills less representative of competition (absent visual cues and requiring movement patterns not seen in a game) would elicit an acute influence on these perceptual-cognitive processes. While no statistically significant evidence of an acute warm-up effect was noted, descriptive indications were present and results may have been confounded by a skill in recalibration. Findings also support expertise research of perceptual-cognitive skill (Broadbent, Causer, Williams, & Ford, 2015; Mann, Williams, Ward, & Janelle, 2007) and research of the handedness advantage in baseball (Goldstein & Young, 1996; Lindsey, 1959). Accordingly, more experienced participants demonstrated more effective decision-making and gaze behaviour abilities than lesser experience participants and opposite-handed batters (lefties) were more accurate at predicting pitch types than like-handed batters (righties). Going forward, it will be essential to creatively balance the need for experimental control with ecological validity (and task representativeness).

4.5 References

Baker, J., Wattie, N., & Schorer, J. (2015). Defining Expertise. In *Routledge handbook of sport expertise* (pp. 145-147): Routledge.

Brand, M. T., & de Oliveira, R. F. (2017). Recalibration in functional perceptual-motor tasks: A systematic review. *Human Movement Science, 56,* 54-70.

Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. R. (2015). Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *European journal of sport science, 15*(4), 322-331.

Causer, J., Harvey, A., Snelgrove, R., Arsenault, G., & Vickers, J. N. (2014). Quiet eye training improves surgical knot tying more than traditional technical training: a randomized controlled study. *The American Journal of Surgery, 208*(2), 171-177.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive psychology, 4*(1), 55-81.

Davids, K., Kingsbury, D., Bennett, S., & Handford, C. (2001). Information-movement coupling: Implications for the organization of research and practice during acquisition of self-paced extrinsic timing skills. *Journal of Sports Sciences, 19*(2), 117-127.

Davids, K. B. S. J. H. C. H., & Jones, B. (1999). Acquiring a frame of reference for practising in selfpaced extrinsic timing tasks: Analysis of co-ordination in skilled volleyballers. *International Journal of Sport Psychology, 30*, 437-461.

De Groot, A. D. (1965). *Thought and choice in chess* (Vol. 4): Walter de Gruyter GmbH & Co KG.

Eivazi, S., Bednarik, R., Tukiainen, M., von und zu Fraunberg, M., Leinonen, V., & Jääskeläinen, J. E. (2012). *Gaze behaviour of expert and novice microneurosurgeons differs during observations of tumor removal recordings.* Paper presented at the Proceedings of the Symposium on Eye Tracking Research and Applications.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological review, 100*(3), 363.

Goldstein, S. R., & Young, C. A. (1996). " Evolutionary" stable strategy of handedness in major league baseball. *Journal of Comparative Psychology, 110*(2), 164.

Gray, R. (2017). Transfer of Training from Virtual to Real Baseball Batting. *Frontiers in Psychology, 8*(2183). doi:10.3389/fpsyg.2017.02183

Kasarskis, P., Stehwien, J., Hickox, J., Aretz, A., & Wickens, C. (2001). *Comparison of expert and novice scan behaviors during VFR flight.* Paper presented at the Proceedings of the 11th International Symposium on Aviation Psychology.

Krause, L., Farrow, D., Reid, M., Buszard, T., & Pinder, R. (2017). Helping coaches apply the principles of representative learning design: validation of a tennis specific practice assessment tool. *Journal of Sports Sciences*, 1-10.

Law, B., Atkins, M. S., Kirkpatrick, A. E., & Lomax, A. J. (2004). *Eye gaze patterns differentiate novice and experts in a virtual laparoscopic surgery training environment.* Paper presented at the Proceedings of the 2004 symposium on Eye tracking research & applications.

Lindsey, G. R. (1959). Statistical Data Useful for the Operation of a Baseball Team. *Operations Research, 7*(2), 197-207.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology, 29*(4), 457-478.

O'Neill, E. C., Kong, Y. X. G., Connell, P. P., Ong, D. N., Haymes, S. A., Coote, M. A., & Crowston, J. G. (2011). Gaze behavior among experts and trainees during optic disc examination: does how we look affect what we see? *Investigative ophthalmology & visual science, 52*(7), 3976-3983.

Official Rules of Baseball - Canadian Content, 10 (2018).

Pinder, R. A., Renshaw, I., & Davids, K. (2009). Information–movement coupling in developing cricketers under changing ecological practice constraints. *Human Movement Science, 28*(4), 468-479.

Rosalie, S. M., & Müller, S. (2012). A model for the transfer of perceptual-motor skill learning in human behaviors. *Research Quarterly for Exercise and Sport, 83*(3), 413-421.

Shim, J., Carlton, L. G., Chow, J. W., & Chae, W.-S. (2005). The use of anticipatory visual cues by highly skilled tennis players. *Journal of Motor Behavior, 37*(2), 164-175.

van Andel, S., Cole, M. H., & Pepping, G.-J. (2017). A systematic review on perceptual-motor calibration to changes in action capabilities. *Human Movement Science, 51*, 59-71. doi:10.1016/j.humov.2016.11.004

Wilson, M. R., Vine, S. J., Bright, E., Masters, R. S., Defriend, D., & McGrath, J. S. (2011). Gaze training enhances laparoscopic technical skill acquisition and multi-tasking performance: a randomized, controlled study. *Surgical endoscopy, 25*(12), 3731-3739.

Withagen, R., & Michaels, C. F. (2002). The calibration of walking transfers to crawling: Are action systems calibrated? *Ecological Psychology, 14*(4), 223-234.

Appendices

Appendix A. REB Approval from the University of Ontario Institute of Technology

Approval Notice - REB File #14950 (conditions addressed fro July 13, 2018 letter) Inbox x

researchethics@uoit.ca
to Wattie, McCue, researchethics ▾

Oct 1, 2018, 3:28 PM

Date:	*October 01, 2018*
To:	*Nick Wattie*
From:	*Janice Moseley, Research Ethics Officer, for the Research Ethics Board*
File # & Title:	*14950 - Assessing the effect of de-coupled batting drills on the gaze behaviour of elite baseball players*
Status:	***APPROVED (conditions addressed from July 13, 2018 letter)***
Current Expiry:	***July 01, 2019***

Notwithstanding this approval, you are required to obtain/submit, to UOIT's Research Ethics Board, any relevant approvals/permissions required, prior to commencement of this project.

The University of Ontario, Institute of Technology Research Ethics Board (REB) has reviewed and approved the research proposal cited above. This application has been reviewed to ensure compliance with the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2 (2014)) and the UOIT Research Ethics Policy and Procedures. You are required to adhere to the protocol as last reviewed and approved by the REB.

Continuing Review Requirements (all forms are accessible from the IRIS research portal):

- **Renewal Request Form**: All approved projects are subject to an annual renewal process. Projects must be renewed or closed by the expiry date indicated above ("Current Expiry"). Projects not renewed 30 days post expiry date will be automatically suspended by the REB; projects not renewed 60 days post expiry date will be automatically closed by the REB. Once your file has been formally closed, a new submission will be required to open a new file.
- **Change Request Form**: Any changes or modifications (e.g. adding a Co-PI or a change in methodology) must be approved by the REB through the completion of a change request form before implemented.
- **Adverse or Unexpected Events Form**: Events must be reported to the REB within 72 hours after the event occurred with an indication of how these events affect (in the view of the Principal Investigator) the safety of the participants and the continuation of the protocol (i.e. un-anticipated or un-mitigated physical, social or psychological harm to a participant).
- **Research Project Completion Form**: This form must be completed when the research study is concluded.

Always quote your REB file number (**14950**) on future correspondence. We wish you success with your study.

Janice Moseley
Research Ethics Officer
researchethics@uoit.ca

Appendix B. REB approval from Durham College

DURHAM COLLEGE
SUCCESS MATTERS

Print Form

Research Ethics Board
External Researcher Institutional Permission Request Form

For office use only:

Date Received: Sept 7/18 REB#: 170-1819 Mathew McCue

Section 1.0 Purpose

All researchers planning to conduct research involving human participants and wishing to access Durham College faculty, staff, students, or resources, must first obtain institutional permission to conduct the research before applying for ethical approval from the Research Ethics Board (REB). Institutional permission is intended to ensure that the research does not unreasonably interfere with Durham College operations. Permission may or may not be granted on the basis of the project's costs, effort, risk, impact on members of the college, and/or impact on institutional resources. **Research ethics approval does not constitute institutional permission.**

Section 2.0 Instructions

Please submit this form to the REB along with your completed ethics application, and the REB coordinator will coordinate with the Office of the Vice-President, Academic or other Vice-President as appropriate on your behalf to facilitate the institutional permission process, prior to the ethical review of the REB application.

For a Microsoft Word version of this form, contact reb@durhamcollege.ca.

Section 3.0 Project Information

Section 3.1 Principal Investigator (PI) Information

Name:	Dr. Nick Wattie
Position:	Assistant Professor
School:	University of Ontario Institute of Technology
Email Address:	Nick.wattie@uoit.ca

Section 3.2 Team Information (Faculty Supervisor/Co-investigator)

	Name	Position	Email Address
Add Row Delete Row	Matt McCue	MHSc Graduate Student	Matthew.mccue@uoit.net

Section 4.0 Signature of Institutional Permission

Institutional approval granted by:

Signature of Vice-President, Academic/ Vice-President:	
Full Name:	Dr. Elaine Popp
Date:	September 7, 2018

*(if you are unable to add an electronic signature, print off this page, sign it and scan a PDF copy, and email it to reb@durhamcollege.ca).

Appendix C. Pre-study Questionnaire

Pre-study Questionnaire

Assessing the effect of de-coupled batting drills on the gaze behaviour of elite baseball players

Participant Information

Date of Birth: ____________ ____________ ________________

Day Month Year

Bats (please circle): Right Left Switch

Playing Experience

1. Have you ever received an athletic scholarship from an NCAA or NAIA institution?

Yes No

2. Have you participated on an Ontario University Athletics (OUA) or Ontario Colleges Athletic Association (OCAA) varsity baseball team?

Yes No

3. Have you participated in any of the following semi-professional/amateur leagues? If yes, please indicate when.

Canadian American Association of Professional Baseball (CANAM)	YES	NO	Year(s) played:
Intercounty Baseball League	YES	NO	Year(s) played:
Northwoods League	YES	NO	Year(s) played:
Western Major Baseball League	YES	NO	Year(s) played:

Video Simulation/Practice Experience

5. Have you had any experience with video simulations through research or practice?

Yes　　　　No

If yes, please specify:

6. What is the average velocity of a pitching machine in your practice environment?

__________ **(mph)**

Health

7. Are you currently experiencing any health concerns that may prevent you from swinging a baseball bat?

Yes　　　　No

If yes, please specify:

8. Do you have 20/20 vision?

Yes　　　　No

If no, do you wear corrective contact lenses?

Yes　　　　No

9. Would you like to be emailed a report of your results? (NOTE: only your own data will be shared with you. All other dissemination will be group aggregate data).

Yes　　　　No

Disclaimer and signature

I certify that my answers are accurate and adequately depict my playing experience and current health status.

Signature:　　　　***Date:***

Appendix D. Informed Consent

Informed Consent

Assessing the effect of batting drills on the gaze behaviour and batting performance of elite baseball players

You are invited to participate in a study at the University of Ontario Institute of Technology. This consent form is only part of the process of informed consent. This should give you a basic idea and understanding of what the study, and your participation entails. If you would like more information on anything you see here, or information not-included, please do not hesitate to get in contact with Matt McCue or Dr. Nick Wattie. Please take the time to read this form carefully, and to understand following information.

Study Name:
Assessing the effect of de-coupled batting drills on the gaze behaviour of elite baseball players

Researchers:

Mr. Matt McCue, BSc
MHSc (Candidate)
Faculty of Health Sciences
University of Ontario Institute of Technology
Matthew.McCue@uoit.net

Dr. Nick Wattie, PhD
Assistant Professor
Faculty of Health Sciences
University of Ontario Institute of Technology
nick.wattie@uoit.ca

Purpose of Research:

Warming up prior to competition is important for athletes as it affords time dedicated to muscle loosening and focusing in on the task at hand. We do know that warming up is great for muscle health, but we do not know if how we warm-up has an influence on performance. Baseball coaches use a variety of drills in the practice and/or warm-up environment to prepare athletes for competition. Specifically, hitters will routinely participate in drills such as: tee-work, front-toss, pitching machine batting practice and coach-thrown batting practice. The purpose of our study is to take a deeper look at these drills and analyze how they may impact gaze behaviour and batting performance during competition.

Study Information:

If you choose to voluntarily participate in this study, the following methods will be followed:
You will be asked to bring any baseball equipment typically brought to a game (i.e., bat, helmet, batting gloves, and glove). Upon arrival, you will be instructed to conduct your regular warm-up protocol prior to taking batting practice (i.e., running and stretching).

Once ready, you will perform twenty swings in one of four conditions. The four conditions are traditional baseball drills that are routinely incorporated into every day practice or warm-up. You will be asked to do one of the following: hit a ball off of a standard Tanner Tee™, swing at balls delivered from a pitching machine or certified coach, or complete twenty ‘dry’ swings with no ball involved.

After warm-up, you will proceed to a video simulation. You will be equipped with a mobile eye tracker (similar in structure and size to regular sunglasses) and asked to predict final location and types of twenty simulated pitches. The entire process will take approximately four hours.

Risks and discomforts:

A possible risk associated with the study is the chance of being hit with a ball during the warm-up protocol. We will ensure the pitching machine is frequently re-calibrated to the centre of the strike zone. Additionally, we will instruct the coach throwing batting practice to only deliver pitches in the middle of the strike zone. We ask that you only agree to participate if you believe forty swings will not cause or aggravate any injuries. Campus first aid staff will be on hand to assist with any injuries or discomfort you may experience. Although there may be minor risks associated with participating, you will not be asked to do anything out of the ordinary or atypical of your usual baseball participation.

Benefits of Research and Benefits to you:

As a participant in this study, you will be given the option to obtain a report of your gaze behaviour recorded during the video simulation. The data found in the report may be used to contextualize what your eyes are actually fixating on during a swing. This data may be used to optimize your gaze behaviour and pre-pitch mechanics.

Results from this study will also add to the growing body of literature focused on representative learning design and perception-action coupling in sport. Coaches, scouts and players in the baseball community may use the information we disseminate as a tool to help design optimal practice and warm-up environments. This evidence-based research in high performance sport is also critical for youth sport development and elite sport development programs. A lot of money is poured into these programs and the findings of our study may aid the justification for their practice regime.

Voluntary Participation:
Your participation in all components of this research (in whole or in part) is completely voluntary. You should note, that if you choose to not participate, this will not affect your relationship, or the nature of your relationship with the researchers or with staff at the University of Ontario Institute of Technology either now or in the future.

Withdrawal from the study:
You may stop participating in the study at any point during data collection, for any reason, if you so decide. Once data collection is complete, you may withdraw your data from this study for any reason until January 1st, 2019. Your decision to stop participating in the study, or refusal to answer particular questions will not affect your relationship with the Principal Investigator, student lead, or the University of Ontario Institute of Technology. Statement, if you withdraw from the study at any point your data will be immediately and permanently deleted.

Confidentiality:
All data collected and contained in the study will be treated as confidential. For this data set, all personal identifiers will be removed from the data set, and the subjects will be organized by number rather than names. This practice ensures that it is not possible to trace any data back to a specific individual. You consent to have your data used for the purpose of research in the form of a thesis, as well as academic outputs such as: presentations, conferences, and peer reviewed publications. All results of the study will be presented as aggregate data, and no individual will ever be presented. All qualitative and quantitative data will be compiled and stored on secure servers, password protected computers and files that only the student lead – Mr. Matt McCue, and principal investigator – Dr. Nick Wattie, will have access to. No individual data will be presented during the dissemination of the results. Data will be stored for up to 5 years, after which point data will be destroyed. If you request a report, you will only have access to your individual data once the data analysis procedure is finished.

Confidentiality will be provided to the fullest extent possible by law.

Participants Concerns and Reporting:
If you have any questions concerning the research study or experience any discomfort related to the study, please contact the researcher Matt McCue at 905-510-6822 or Matthew.mccue@uoit.net.

Any questions regarding your rights as a participant, complaints, or adverse events may be addressed to Research Ethics Board through the Research Ethics Coordinator – researchethics@uoit.ca or 905.721.8668 x. 3693 or reb@durhamcollege.ca.

Inclusion and participation in this study requires your consent to release gaze behaviour and pitch prediction data. All participants need to have 20/20 or corrected to 20/20 vision.

All personal identifiers will be removed from our dataset and no individual data will be presented in graduate thesis, peer-reviewed publications, abstracts, and conference presentations. Individual data will not be shared with anyone and may only be accessed by Matt McCue and Dr. Nick Wattie. By signing this consent form, you agree that your data can be used for the purpose of this study (as described above).

If you agree to participate in this study, we ask that you please complete the background questionnaire (see next page) on your baseball experience and history and return it with this completed consent form.

This study has been approved by the UOIT Research Ethics Board [REB #14950] on [July 13th, 2018] and the Durham College REB [REB # 170-1819] on [September 14th, 2018].

Legal Rights and Signatures:

I ____, consent to participate in the *Assessing the effect of batting drills on the gaze behaviour and batting performance of elite baseball players* research project conducted by Matt McCue. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My signature below indicates my consent for this project and the use of my data for secondary research purposes.

Signature:___________________________
Date:___________________

Participant:

Signature:_______________
Date:___________________

Student researcher: Matthew McCue

Appendix E. Information Letter for Athletes

Assessing the effect of batting drills on the gaze behaviour and batting performance of elite baseball players

You are invited to participate in a study at the University of Ontario Institute of Technology.
My name is Matt McCue and I am a Masters student currently seeking volunteers for my thesis project that focuses on elite baseball players.

I am a former collegiate baseball player and a current player in the Intercounty Baseball League. As such, I have spent countless hours driving baseballs in to open fields or secured netting without much thought. However, recently my worlds of science and sport have collided and I have begun to question how the drills used every day at baseball practice (i.e., tee-work, front-toss, coach-thrown batting practice, and pitching machine batting practice) impact batting performance. Specifically, I would like to see how these drills influence gaze behavior (where and how long you look at specific cues) and batting performance.

If you choose to voluntarily participate in this study it will involve the following procedure. You will be asked to bring any baseball equipment typically brought to a game (i.e., bat, helmet, batting gloves, and glove). Upon arrival at the UOIT campus in Oshawa, you will be instructed to conduct your regular warm-up protocol prior to taking batting practice (i.e., running and stretching). Once ready, you will perform twenty swings in one of four conditions. The four conditions are traditional baseball drills that are routinely incorporated into every day practice or warm-up. You will be asked to do one of the following: hit a ball off of a standard Tanner Tee™, swing at balls delivered from a pitching machine or certified coach, or complete twenty 'dry' swings with no ball involved. After warm-up, you will proceed to a video simulation. You will be equipped with a mobile eye tracker (similar in structure and size to regular sunglasses) and asked to predict final location and types of twenty simulated pitches while the eye tracker measures where you are looking. The entire process will take approximately two hours.

Athletes that participate in this study will have access to our rare mobile eye tracker and will be issued a report of their gaze behaviour once the study is complete. If you choose not to participate in this study, but would like to receive a summary report of the overall study findings, that can also be arranged. This information may be used to optimize ball-tracking during batting and allow you to understand what you are looking at during a pitch. The results of this study may also suggest what drills are ideal for calibrating your vision before you bat.

If you have any comments or questions, please feel free to email me at this address Matthew.mccue@uoit.net or my supervisor at Nick.Wattie@uoit.ca or if you prefer to call you can reach me at 905-510-6822. This study has been approved by the UOIT Research Ethics Board [REB #14950] on [July 13th, 2018]. If you are interested in participation, please fill out the informed consent and pre-study questionnaire attached.

Thank you for your consideration,

Appendix F. Checklist for athlete briefing – Recruitment process

Checklist for Athlete Meeting

- ☐ Would like to invite you to participate in a study at UOIT
- ☐ Masters student currently seeking volunteers for my thesis project
- ☐ Would like to see how drills used in practice/warm-up influence gaze behaviour
- ☐ Voluntary nature of participation
- ☐ Protocol: Bring equipment to UOIT that you would typically bring to a game. Will be instructed to conduct regular warm-up protocol prior to taking batting practice (BP). Twenty swings in one of four conditions (tee, pitching machine BP, regular BP, control).
- ☐ Equipped with a mobile eye tracker and you will face a video simulation. Entire process should take approximately four hours.
- ☐ If participants would like, we will provide them with a report of their gaze behaviour which they can use to optimize ball-tracking during batting.
- ☐ Reiterate voluntary nature of study and introduce print copies of informed consent/pre-study questionnaire

Appendix G. Recruitment email for coaches – Recruitment Process

Hi Coach,

My name is Matt McCue and I am a Masters kinesiology student at the University of Ontario Institute of Technology. I'm also a former college baseball player and a current participant in the Intercounty Baseball League. I am reaching out as I am seeking volunteers to participate in my thesis project that focuses on elite baseball players.

As a coach of a high performance team, I'm sure you have noticed the influx of advanced metrics and cutting-edge technology in baseball batting. While this may be useful, we still don't quite understand how different types of batting drills may impact an athlete's batting performance. My study aims to look at this relationship and is designed to analyze drills like: front-toss, tee-work, coach-thrown batting practice and pitching machine batting practice.

Athletes that participate in this study will have access to our rare mobile eye tracker and will be issued a report of their gaze behaviour once the study is complete. This information may be used to optimize ball-tracking during batting and allow the batter to understand what they are looking at during a pitch. The results of this study may also suggest what drills are ideal for calibrating a hitter's vision before they bat. If interested, coaches in your league will be provided with a summary report of how the different drills influenced gaze behaviour.

If you could share the nature of my study with your players, I would greatly appreciate it. If you have any comments or questions or your players are interested in participation, please feel free to email me at this address Matthew.mccue@uoit.net or my supervisor at Nick.Wattie@uoit.ca or if you prefer to call you can reach me at 905-510-6822. I have also attached additional information about the study design if you are interested. This project has been approved by the Research Ethics Board at UOIT.

If it would be helpful to meet in person and discuss this study with you and/or your players, we can certainly arrange a time convenient for you.

This study has been approved by the UOIT Research Ethics Board REB 14950 on July 4, 2018.

Thank you for your consideration,

Matt McCue