Pupillometry as a measure of cognitive load during a motor task: Comparing analogy learning to traditional coaching methods

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Abstract

Analogies are thought to reduce cognitive load during motor skill acquisition, yet a reliable and direct measure of cognitive load during movement remains elusive. This thesis seeks to contribute to the existing gap by exploring the use of pupillometry as a potential tool to evaluate cognitive load during a hockey push-pass task. Additionally, the study explores whether analogy instructions contribute to consistency in mental effort and performance compared to discovery and explicit instructional approaches.

Chapter One provides a comprehensive review of relevant literature, setting the stage for the further investigation. In Chapter Two, an experiment examines pupil dilation in dual-task conditions versus single-task conditions during hockey push-passes. Results revealed significant differences in pupil dilation for single task versus dual task performance. The study also evaluates pupillometry and performance across analogy, discovery, and explicit instruction groups, finding no significant differences.

Chapter Three summarizes key findings and delves into their implications. The results suggest pupillometry's potential as an accurate measure of cognitive load during motor learning, with considerations for further refinement being addressed. The thesis concludes by emphasizing the need for additional research to deepen our understanding of the relationship between pupillometry and cognitive load measurement during a motor task.

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Embarking on my Master's journey has been marked with profound learning and growth. Little did I anticipate that five years later, I would still be immersed in the rich academic tapestry of the University of Waikato.

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Thesis Organisation

This thesis is organized into three chapters. Chapter One offers a comprehensive review of relevant literature, covering topics such as working memory, implicit learning, analogy learning, including discoveries and criticisms, and various methods of measuring cognitive load, with an introduction to pupillometry. Chapter Two delves into the rationale behind the experiment, introducing hypotheses and presenting original research designed to explore how pupillometry contributes to our understanding of cognitive load in different learning conditions, particularly testing previous research findings associated with analogy learning. Finally, Chapter Three proposes a conclusion derived from the experiment's findings, highlights acknowledged limitations, and proposes avenues for future research.

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Chapter One

Literature Review

1.1 Working Memory

Working memory is a system with limited capacity and duration, where conscious processing occurs to manipulate new information for learning (Abernathy et al, 2007; Baddeley, 1992; Marcus et al., 1996; Simon 1974). Miller (1956) proposed that the capacity of the working memory system was seven plus or minus two items of information at any given time. The average memory span for new information therefore typically has a capacity between five and nine items. Working memory serves as the gateway to memory consolidation, which is formed in long-term memory. If nothing has entered the long-term memory system, then nothing has been learned. Long-term memory does not have the same limitations as working memory because the information is stored in a network of higher units called cognitive schemata (Schnotz & Kürschner, 2007). According to Kane and Engle (2002), working memory is essential because it allows a person to efficiently process information relevant to the goal of a task while ignoring or suppressing irrelevant information. However, as a result of working memory having a limited capacity and time limit, it can be difficult for a learner to process multiple pieces of information simultaneously (Paas & Sweller, 2005). The relationship between the limitations of working memory and the necessity for effective information processing highlights the cognitive difficulties encountered by learners in multimedia settings.

1.1.1 Implicit Learning

Working memory, with its capacity for focused processing, may influence the extent to which learning occurs by shaping the cognitive processes involved in the acquisition and retention of task-related information. The learning of a task or skill implicitly results in development of knowledge that is less accessible consciously and cannot be easily articulated (Hayes & Broadbent, 1988; Masters, 1992; Reber, 1989). Implicit learning is ‘unselective’, in that the learner acquires knowledge about a complex concept without deliberate intention (Berry & Dienes, 1993; Hayes & Broadbent, 1988). In contrast, explicit learning is the deliberate use of problem-solving strategies to generate knowledge (Masters, 1992). Conventional coaching approaches often rely on explicit instructions for skill teaching. However, evidence suggests that one benefit of implicit learning is its potential for greater durability when compared with explicit learning. For example, Allen and Reber (1980) found that two years later participants had retained implicit but not explicit knowledge of the underlying features of an artificial grammar learning exercise.

Implicitly acquired knowledge has also demonstrated greater resilience under pressure compared to knowledge acquired explicitly. Lam et al. (2009b) found that the application of conscious control, as observed in the explicit group, placed a significant demand on working memory, leading to performance breakdowns when introducing a secondary load during a basketball shooting task. Masters (1992) had participants learn a golf putting task either implicitly or explicitly, using a concurrent secondary task to limit working memory resources. Performance under pressure was less likely to deteriorate in the implicit learning group, where participants recalled fewer rules compared to the explicit learning group. Hardy et al. (1996) replicated these results, confirming that using a secondary task may successfully induce implicit motor learning. However, both Masters (1992) and Hardy et al. (1996) found that the implicit learners displayed lower levels of performance than the explicit learners. This prompted a critical evaluation of the advantages of implicit learning methods in comparison to explicit methods within the realm of skill acquisition. If the introduction of a secondary task in a real-world sports setting pose challenges, such as less effective skill execution compared to traditional coaching methods, it becomes imperative for research to investigate alternative approaches that foster implicit motor learning, aiming to harness its proposed benefits. Additionally, it is important to acknowledge the potential difficulty of teaching skills while simultaneously handling a secondary task in a coaching environment enhancing the need for a more efficient implicit learning approach.

1.2 Analogy Definition

Masters (2000) suggested the use of an analogy to guide learners towards appropriate movement patterns without providing explicit instructions. Analogies seem to bypass the need for explicit verbal information; instead, they leverage the resemblance of a familiar phenomenon or situation to the skill being acquired.

An analogy presents a higher-order relationship between the rules of a concept (Abernathy et al., 2007). This basic mechanism can allow processing and understanding of a novel situation in terms of one that the learner is already familiar with (Gentner & Holyoak, 1997). Analogies are intended to restrict the number of explicit rules learnt in a motor task by creating a single "all-encompassing biomechanical metaphor" (Masters, 2000, p.538). Furthermore, analogies can convey a system of related knowledge, not just a collaboration of independent facts (Gentner, 1983). People frequently use analogies unconsciously to clarify unfamiliar concepts by placing them in a more relatable context. The characteristics observed in analogy learning align with the features of implicit learning. Examining the resemblances between analogies and implicit learning techniques led to additional investigation and research in the realm of analogy-based motor learning.

1.2.1 Analogy Learning

Liao and Masters (2001) investigated participants learning a forehand topspin shot in table tennis through explicit, implicit, or analogy conditions. In the analogy and implicit groups, learners accumulated fewer rules compared to the explicit group, suggesting that analogy learning may be an effective method for implicit skill acquisition. Krause et al. (1999) examined a common analogy used by basketball coaches that promoted backspin on a free throw, which was believed to increase the chances of success. The analogy was to finish a shot as if "your hand is reaching for a cookie from a cookie jar" (Krause et al., 1999, pp. 72-73). Lam et al. (2009b) employed this specific analogy to instruct a group of participants in a basketball shooting task. The performance of these participants remained unaffected by a pressure manipulation, while those taught with explicit instructions experienced a decline in performance under pressure. Participants also reported fewer rules in the analogy group, indicating that they had a restriction in explicit processing of the task. Van Duijn et al. (2019) employed an analogy instruction in a hockey push-pass task and observed that the group receiving analogy instruction demonstrated better pass-accuracy when concurrently engaged in a decision-making task compared to the explicit instruction group. Other studies have also found that participants in an analogy learning group reported fewer rules and had a more robust performance under a pressure condition when compared with explicit learning groups (Kim et al., 2021; Lam et al., 2009a; Liao & Masters, 2001; Lola & Tzetzis, 2021; Poolton et al., 2006).

1.2.2 Criticisms

Analogical instructions have demonstrated greater effectiveness in fostering implicit learning compared to secondary tasks, especially in maintaining skill execution without a decline in performance. While analogies may provide benefits in the application of implicit learning techniques in real-world scenarios, there are critiques regarding the comparison of analogy learning to explicit learning conditions.

A point of critique regarding analogy learning is the potential imbalance between the number of explicit instructions and analogy instructions (Bobrownicki et al., 2018). For example, Lam et al. (2009b) used eight instructions in the explicit condition and a single instruction in the analogy condition. Other studies have a larger number of instructions in the explicit condition compared with a single analogy in the implicit condition (Hosseini & Papoli, 2023; Koedijker et al., 2011; Tse et al., 2017; van Dujin et al., 2019). This suggested that an analogy instruction may benefit a learner due to the smaller volume of information rather than the type of learning it encourages (Bobrownicki et al., 2018). Certain studies have equated the number of instructions for both the analogy and explicit groups (Tse et al., 2017), while others have introduced an additional instruction for the analogy group compared to a control group (Komar et al., 2014). In their study, Komar et al. (2014) employed an analogy instruction to teach a crucial aspect of the skill in addition to the two explicit rules provided to both the analogy and control groups. While a few studies have endeavoured to equate the number of rules between the analogy and explicit groups (Bobrownicki et al., 2015; Schücker et al., 2010; Tse et al., 2017), the predominant trend in research has been to allocate more instructions to the explicit group as opposed to the analogy group.

Furthermore, for analogies to be advantageous in task learning, they must be comprehensible and relevant to the individual (Bobrownicki et al., 2018). Liao and Masters (2001) found that a right-angled triangle analogy used in a table tennis topspin task was successful with English speakers, whereas Poolton et al. (2003) found that the same analogy caused confusion when carrying out a similar task with Chinese speaking participants. Gentner (1983) indicated that if an analogy doesn't give appropriate abstractions, it won't be effective in the portrayal of a concept. Poolton et al. (2007, p. 377) found that a different analogy, "move the bat as though it is traveling up the side of a mountain" more successfully promoted implicit learning in the Chinese population. Encountering a culturally relevant analogy demonstrated greater efficacy in the learning process. Generating a suitable analogy for specific skills and populations may require robust contemplation and experimentation. In individuals with Parkinson's disease, Jie et al. (2016) found that a notable benefit of analogies is their adaptability to cater to the unique needs of each person. Individualized analogies have the potential to serve as a potent tool for tailoring learning experiences, allowing individuals to apply information based on their own perceived challenges with a skill.

1.3 Cognitive Load

Cognitive load involves the processing of new information within the confines of working memory. Cognitive load refers to the total mental effort being utilized in working memory at a specific moment. (Haji et al., 2015; Paas & Van Merriënboer, 1993; Sweller et al., 1998; Sweller & Chandler, 1991). The integration of analogies may serve as a means to ease the cognitive load, simplifying the learning of new skills. The investigation into cognitive load involves exploring its numerous components and considering the wide-ranging implications inherent in this cognitive phenomenon.

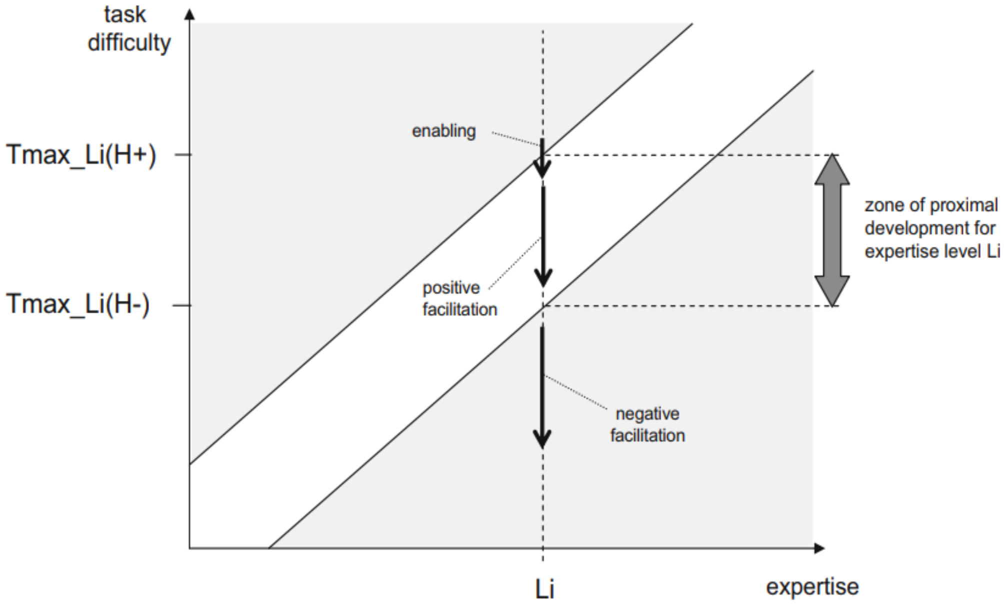
1.3.1 Intrinsic, Extraneous and Germane Load

Cognitive Load Theory (CLT) was developed with a focus on decreasing the demand of problem solving on working memory capacity for students (Sweller, 1976). The fundamental concept of CLT is that instructions must align with the cognitive structure for effective learning to take place. The theory identifies three distinct components of cognitive load: intrinsic, extraneous, and germane loads. Intrinsic load is defined as the amount of load that must be processed about the natural complexity of the task, extraneous load is defined as the amount of load that is caused by the way in which the instruction/s given are formatted (Schnotz & Kürschner, 2007), and germane load is defined as the load that requires conscious processing to help develop information into schemata to secure it into long-term memory (Sweller et al., 1998). According to the original CLT, the total cognitive load is the sum of all three of these. For the most effective learning, Sweller et al., (1998) suggested designing instructions that reduce extraneous load to prevent overloading working memory. A method of achieving this was to increase germane load to encourage learners to form cognitive schemata. If the number of elements to be processed together exceed working memory capacity, some elements need to be combined in a higher order schema to be understood (Marcus et al. 1996; Schnotz & Kürschner, 2007). When delving into a new sport, individuals are continuously acquiring the vital skills required for active participation. If their working memory capacity is overwhelmed with numerous new instructions to remember, improvement in the sport may become more challenging. Acquiring new skills by establishing cognitive schemata in long-term memory early could enable learners to accumulate more knowledge by freeing up space within the working memory system.

According to CLT, many instructional techniques that are commonly used have an unnecessarily high extraneous load that disrupts learning (Sweller & Chandler, 1994; Sweller 2003, 2005; Schnotz & Kürschner, 2007). In the original CLT, it was assumed that intrinsic load was fixed, with extraneous and germane loads as the only manipulable factors. However, Schnotz and Kürschner (2007) proposed that intrinsic load for a particular task could vary based on the learner's expertise. This insight prompts a more nuanced consideration of how instructional techniques, including the use of analogies and explicit learning, can effectively manage intrinsic, extraneous and germane load in the learning process. The idea of adapting intrinsic load to the learner's expertise was proposed in Vygotski's (1963) Zone of Proximal Development (see Figure 1).

Figure 1

Zone of Proximal Development



Note. From "A Reconsideration of Cognitive Load Theory", by W. Schnotz and C. Kürschner, 2007, *Educational Psychology Review, 19*, p. 486

The Zone of Proximal Development highlights the boundaries within which instructional help can facilitate or hinder learning. If instructional help reduces the task difficulty that could otherwise be solved with only high mental effort, it has a facilitating function. Positive facilitation remains within the confines of a learner's proficiency, ensuring that task difficulty aligns appropriately. Conversely, negative facilitation lowers task difficulty to a degree where it no longer aligns with the learner's expertise and prevents them from encountering challenges which promote growth and development.

Vygotski (1963) defined the lower limit of the Zone of Proximal Development as the most difficult task a learner can be successful at without external help and the upper limit as the most difficult task a learner can be successful at with external or instructional help. Instructional help has an enabling function if it reduces the difficulty of a task that would otherwise be impossible. Enabling can occur through the reduction of cognitive load for a task. If an analogy reduces the overall cognitive load for a task, it has the potential to enhance the learning of a new skill without overwhelming a novice learner. This, in turn, could lead to consistent performance both over time and under pressure. When given information in a segregated format through explicit instructions, learners must expend extra effort to retain information in working memory while navigating attention across various information sources (Schnotz & Kürschner, 2007). This creates a heavier extraneous load on their working memory. An analogy's ability to present information in a cohesive manner might offer the chance to reduce both extraneous and intrinsic load, extending the upper limit of the Zone of Proximal Development. Strategic utilization of analogies presents a promising pathway to refine instructional methods and elevate overall learning outcomes.

1.3.2 Measuring Cognitive Load

Incorporating cognitive load considerations into an experimental design has been achieved seamlessly, but the difficulty for researchers lies in identifying an accurate and precise measure of cognitive load. Several methods have been utilised to measure cognitive load, which are explained below.

1.3.3 Subjective Rating Scale

The subjective rating scale is one of the most widely used cognitive load measures (Paas, 1992). When an individual is presented with a cognitive load rating scale, the assumption is that they can self-report their mental difficulty levels for a task. Subjects who perceive a task as easier often rate its difficulty lower compared to individuals who find the task more challenging (Bratfisch et al., 1972). The qualitative nature of a subjective rating scale enhances the depth of knowledge and provides valuable insights into an individual’s perception of how difficult a task is. However, Schmeck et al. (2014)

observed that the timing of administering cognitive load rating scales during a problem-solving experiment had an influence on the data collected. It was found that the reliability of a subjective rating scale could decrease due to changes in learning resulting from skill adaptation, fluctuations in motivation, and emotional shifts throughout a task. Another limitation of this method is the potential for response biases, where discrepancies may arise between participants' perceptions and actual performance, given the subjective nature of the rating (Zheng & Greenberg, 2017). Overall, a subjective rating scale gives us a glimpse into the cognitive load an individual undergoes during a task; however, it can restrict the accurate assessment of cognitive load as the task unfolds.

1.3.4 Dual Task Paradigm

A frequently utilized measure for evaluating cognitive load is to assess participants' performance in the primary task while they are simultaneously involved in a secondary task, often referred to as the dual-task paradigm. Secondary task loading can provide a indication of cognitive resources being used up by the primary task (Kerr, 1973). The premise is that due to the limited capacity of working memory, resource allocation needs to be divided between the two tasks (Schnotz & Kürschner, 2007).

Performance of a motor task without a secondary task is usually superior to performance with a secondary task (Maxwell et al., 2000). Adding a secondary task has shown to prevent the generation of explicit rules about performance by limiting the working memory resources available for the processing of information (Hardy et al., 1996; Masters, 1992). Therefore, an attention demanding secondary task reduces the working memory capacity available for movement execution in a primary task (Koedijker et al., 2011; Maxwell et al., 2003). Analysing the performance of the primary task allows researchers to understand how the cognitive load from concurrent secondary tasks influences the efficiency and effectiveness of the main motor activity.

1.3.5 Physiological Measures

Various physiological measures operate under the assumption that alterations in cognitive load are seen as changes in specific physiological states. One measure that has been utilised is the galvanic skin response (GSR), which measures conductivity of the human skin (Schnotz & Kürschner, 2007; Shi et al., 2007). Research has demonstrated that GSR serves as an objective measure of cognitive load, regulated by skin conductivity (Nourbakhsh et al., 2012; 2017). A challenge associated with GSR data is its susceptibility to variation based on different experimental conditions (Haapalainen et al., 2010). The signal quality of GSR may also be influenced by unrestricted motion, where inadequate contact between the wearable device and the skin diminishes GSR signal quality (Gautam et al., 2018; Radhakrishnan et al., 2021).

Another physiological measure, electroencephalography (EEG), provides high temporal resolution for the tracking of cognitive activity via electrical signals from the brain (Janelle et al., 2000; Zheng & Greenberg, 2017). In stationary tasks, EEG has commonly been employed to measure cognitive load (Anderson et al., 2011; Gumilar et al., 2021). EEG faces constraints when motion introduces disruptions in the data, potentially causing electrical interference rather than a precise measurement of cognitive load. (Antonenko et al., 2010; Berka et al., 2004). Additionally, Zheng and Greenberg (2017) emphasize that EEG is not readily applicable to studies involving motor movements due to the necessity of attaching flat metal discs to a subject's face and head.

1.3.6 Pupillometry

Pupillometry is a physiological measure that involves assessing the size of the pupils, typically the diameter, with the assumption that the pupil increases with higher cognitive load (Hess & Polt, 1964; Kahneman & Beatty, 1966; Minassian et al., 2004). If we exclude the effect of drugs causing constriction and dilation of the pupils, in broad terms, the pupil responds to three different stimuli: luminosity, emotions and cognitive activity (Seeber & Kerzel, 2012). To protect the retina from damage, the pupil constricts when exposed to excessive amounts of light (Clarke et al., 2003). The pupil also adjusts when an object is approaching or appears in front of the eyes without warning (Ellis, 1981). Changes in emotions and the level of interest in one's surroundings have been identified as factors influencing average pupil size (Hess, 1975).

Pupillometry remains relatively underutilized as a cognitive load measurement tool within motor learning research. Kahneman and Beatty (1966) demonstrated that pupil diameter consistently increased with the growing number of items and digits to be recalled. Additionally, they observed a strong correlation between task difficulty and the dilation of the pupils. As highlighted by Chalkley (2021), pupillometry has been extensively used to measure cognitive load in various other research domains such as educational psychology. Van Gerven et al. (2004) observed an increase in the mean pupil dilation of individuals during the encoding phase of a memory-search task which correlated with a higher load. Additionally, Cavanagh et al. (2014) found that a heightened decision threshold was characterized by greater pupil dilation during challenging decision-making situations. Laeng et al. (2012) asserted that pupillometry is both non-invasive and involuntary. Analysing an involuntary response enhances the ability to assess cognitive load, mitigating potential participant response bias that might occur when individuals try to appease the researcher. One of the biggest advantages of pupillometry as a measure of cognitive load is that it allows the cognitive analysis of individuals while they are performing a motor skill in real-time. Campbell et al. (2019) highlighted the fascinating possibility of delving deeper into the exploration of pupillometry within the field of sport psychology.

Chapter Two

Exploring Cognitive Load: Analysing Dual Task Challenges and Analogy Learning in Hockey Push-Passes

2.1 Introduction

In sports, 'choking'—a phenomenon where performance falls below expectations—is a critical challenge (Beilock & Gray, 2007). The Theory of Reinvestment (TOR) argues that conscious control of movements can lead to choking under pressure (Masters, 1992). TOR suggests that inward attention disrupts automatic skill execution. Studies show that individuals with lower tendencies to reinvest their knowledge don't experience performance deterioration in high-stress conditions (Chell et al., 2003; Masters et al., 1993). Therefore, acquiring a motor skill implicitly, with minimal explicit knowledge, may prove advantageous for performance under pressure-filled environments.

The following study utilised pupillometry to measure cognitive load during hockey push-pass performance. We aimed to verify whether analogy learning promotes implicit learning in novice hockey participants. Mathôt et al. (2018) recommended employing a subtraction baseline correction, where a baseline measure is subtracted from the mean pupillometry reading during the time of interest to derive a corrected pupil size value.

To respond to the criticism raised by Bobrownicki et al. (2018) regarding the disparity in the number of instructions provided to analogy groups compared to control and explicit groups, we streamlined the set of six explicit instructions for the hockey push-pass down to three. Consultation with two hockey coaches ensured that these three rules encapsulated sufficient information about executing a hockey push-pass. In addressing Bobrownicki et al.'s (2018) concern about the need for analogies to be individually meaningful for effectiveness, we presented a brief video demonstrating the action conveyed in the analogy before providing it in written form to participants. The actions specified in the three explicit rules given to the explicit group align with the particular movements conveyed through the analogy instruction. The explicit and discovery groups were instead both exposed to a short video illustrating the performance of a hockey push-pass, serving as a control measure.

Thorough research on a direct measure of cognitive load during motor task learning is lacking. The establishment of such a measure would enable us to explore whether analogies indeed reduce cognitive load, potentially fostering more implicit learning tendencies. While pupillometry has been extensively utilized for measuring cognitive load in various other research fields, its application in the sport sciences for this purpose remains limited (Chalkley, 2021). Our objective was to bridge this gap by utilizing pupillometry to measure cognitive load, offering a distinctive perspective on motor learning during a hockey push-pass task.

To ensure the suitability of our dual task for inducing cognitive load and to establish pupillometry as a valid indicator of cognitive load, we anticipated that, in the pre-test, participants would exhibit significantly larger pupil sizes during the dual task compared to the single tasks. However, following an analogy instruction, we expected minimal pupil dilation for the analogy group during the dual task compared to the single tasks in the post-test. For the discovery group (receiving no additional instructions), we anticipated a significant increase in pupil size in the post-test dual task due to the accumulation of explicit knowledge through hypothesis testing (Liao & Masters, 2001; Raab et al., 2009). A trial-and-error approach, commonly employed in learning new skills without instruction, involves experimenting with different strategies to enhance success which could increase overall cognitive load (Marden et al., 2009; Young, 2009). Similarly, for the explicit group (receiving three instructions), we hypothesized an increase in pupil size in the post-test dual task, attributed to the extraneous load added to the provided information (Schnotz & Kürschner, 2007). Finally, we hypothesized that the performance accuracy of hockey push-passes for the analogy group during the post-test dual task would remain unchanged. In contrast, we anticipated the performance of the discovery and explicit groups would significantly decrease due to an overload on working memory (Plass et al., 2010; Sweller, 2011).

The findings from this study will enhance our understanding of the impact of cognitive load on performance in high-pressure situations. Additionally, it will expand our knowledge of the application of pupillometry in a sports context, offering further insights into the potential utilization of cognitive load measurement within the industry. Utilizing pupillometry as a physiological measure for cognitive load will enhance the collection of objective data concerning its correlation with the learning of a skill.

2.2 Methods

2.2.1 Participants

Nineteen participants took part in the study. Participants were recruited through word of mouth and social media posts. Participants were encouraged to participate by entering a draw to win one of five NZ $100 petrol vouchers. One participant was excluded from the study due to greater than 20 hours of experience playing hockey. The remaining 18 participants were novices at playing hockey, with normal or corrected-to-normal vision and no movement impairments. Two further participants were excluded from the study due to technical errors (i.e., pupillometry data being deleted, low pupil dilation recording). Data analysis was therefore completed for 16 participants (10 males, *M* age = 27.31 years, *SD* age = 10.216 years). Permission from the University of Waikato HECS Divisional Ethics Committee was gained before carrying out the study (Appendix 1). All participants were provided with an information sheet and gave their informed consent before the completion of the experiment (Appendix 2 and Appendix 3, respectively).

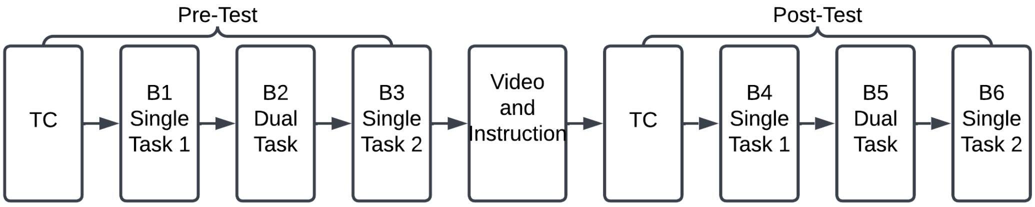
2.2.2 Procedure

Participants were allocated to an analogy group (*n* = 6), an explicit group (*n* = 6), or a discovery group (*n* = 4), using a Latin square design. At the beginning of the experiment, participants were asked to place wearable eye tracker glasses comfortably on their nose as near their eyes as possible and the glasses were calibrated using the recommended calibration method (Tobii Connect, n.d.).

Each participant was asked to perform a tone-counting task, a hockey push-pass task (single task 1), a dual task (a tone-counting task and a hockey push-pass task), followed by another hockey push-pass task (single task 2) in the pre-test and post-test (see Figure 2). In between the pre-test and post-test, the different groups were given different instructions applicable to their group allocation.

Figure 2

Order of Experimental Conditions



Note. TC = Tone Counting; B = Block of ten hockey push-pass trials.

During the tone counting task, participants were seated in front of a wall 500-mm away. They were played a series of high- and low-pitched sounds for one minute (tone counting software: Zhu, n.d.), and they were instructed to count the exact number of high-pitched sounds only (frequency: 1000-ms; lasting duration: 100-ms; high to low ratio: 1 to 1). Prior to single task 1, participants were provided with a definition of a hockey push-pass: “a push-pass is a shot in which the hockey stick guides the ball toward a target without the use of a backswing” (van Duijn et al., 2019, p. 11). Participants were also informed that the ball typically is in contact with the stick and ground during the entire movement, so they should try to get the ball to roll along the ground. During the first hockey push-pass task (single task 1), participants were instructed to pass the ball ten times aiming for the target using a hockey push-pass technique. The target was a black semicircle positioned in the middle of the wall at ground level, which was surrounded by 16 concentric semicircles at 10 cm intervals. The starting position was positioned 340 cm from the target and was indicated with white tape. Participants were instructed to keep doing passes until they were asked to stop, and the experimenter kept track of the number of passes. During the dual task, the participants completed the tone counting task and hockey push-passes simultaneously. Subsequently, another hockey push-pass task was completed (single task 2). A standard field hockey stick (92.7 cm in length) was used on an artificial grass surface in a laboratory at the University of Waikato. A standard-sized tennis ball (between 6.5cm to 6.85cm in diameter) replaced a hockey ball.

Previous studies have shown that analogies benefit learning when they are meaningful to the population they are given to (Gentner, 1983; Poolton et al., 2007; van Duijn et al., 2019). Participants in the analogy group were shown a one-second video of a person sloshing a bucket of water along the ground (see Figure 3) and then subsequently given an analogy instruction typed on an A4 piece of paper (see Table 1). Participants in the discovery and explicit groups were shown a one-second video of someone completing a hockey push-pass (see Figure 3) and then subsequently given a discovery instruction or three explicit instructions respectively typed on an A4 piece of paper (see Table 1). Once a participant received the sheet of paper, they were given 60 seconds to read over and familiarise themselves with the instruction/s given. According to CLT, presenting identical information through different modalities may result in unnecessary processing demands for the skill to be learned (Chandler & Sweller, 1991; Schnotz & Kürschner, 2007). To mitigate this redundancy effect, learners were provided with only a brief video preceding written instructions. This was done to facilitate comprehension of the analogy, while the discovery and explicit groups were provided with a control video demonstrating the execution of a hockey push-pass.

Table 1

Hockey Push-Pass Instructions for Each Group

Group	Instructions
Analogy	Move the hockey stick as if you are sloshing a bucket of water along the ground
Explicit	Hold the hockey stick with a wide grip Step toward the target with your left foot Pull the ball past your left foot toward the target
Discovery	Try to push the ball to the target as exactly as possible

Figure 3

Snapshot of the Video Shown to Each Applicable Group Prior To Instruction

Note. Screenshot of the video shown to the analogy group on the left vs. screenshot of the video shown to the explicit and discovery groups on the right. Videos borrowed from Tina van Duijn with permission.

At the conclusion of the experiment, participants were asked to report any rules that they recalled using during the hockey push passes and to complete a demographics sheet (see Appendix 4). Finally, each participant completed both the Movement Specific Reinvestment Scale and Decision-Specific Reinvestment Scale (MSRS and DSRS respectively, see Appendix 5 and Appendix 6).

2.2.3 Dependent Measures

Pupillometry data. Tobii Pro Glasses 3 is a wearable eye tracker (100 Hz, binocular, firmware 1.28.1granskott) marketed as a valid eye-tracking technology to measure gaze behaviour (e.g., fixations, saccades) and pupillometry (Tobii AB, 2022). The glasses are non-invasive and look similar to reading glasses or sunglasses. The glasses were linked to a recording unit, which was connected to a Dell Precision 3571 model laptop using an ethernet cable. Pupillometry data was processed and analysed using the Tobii Pro Lab software (Tobii AB, 2023). Pupil sizes were calculated from the images of the pupil’s diameter and multiplying it by a scaling factor. The pupillometry data was provided in an absolute measure in millimetres.

Baseline pupillometry data was collected for ten seconds at three different indicators in the experiment: taken at the beginning of pre-test and post-test while seated in front of the wall (before the tone counting task); taken while looking at the target from behind the white tape marker at the beginning of each block of hockey push-passes; and taken while looking at the ball on the ground near the white tape marker at the beginning of each block of hockey push-passes. However, we opted to establish the baseline measure based on the participants' gaze solely directed at the ball since, during our period of interest, participants predominantly focused on the ball. An initial correlation analysis was conducted on the baseline values from each participant looking at the ball before each block of hockey push-passes (B1, B2, B3, B4, B5, B6). Bonferroni adjustments were applied. All baseline values were highly correlated with each other (see Table 2). Given the strong correlations, and to resolve missing baseline values, we used an average of all values as our baseline for each participant in the remaining analyses.

Table 2

Correlations for Each Ball Focused Baseline Value Taken Before Each Corresponding Block of Hockey Push-Pass Trials

	n	*M*	SD	B1	B2	B3	B4	B5
B1	15	4.99	0.77	–				
B2	15	5.03	0.78	0.980*	–			
B3	14	4.87	0.74	0.976*	0.981*	–		
B4	15	4.84	0.74	0.943*	0.962*	0.932*	–	
B5	14	4.99	0.80	0.965*	0.977*	0.963*	0.939*	–
B6	13	4.96	0.67	0.988*	0.986*	0.981*	0.941*	0.969*

Note. *N* = 16, *M* = mean, SD = standard deviation. 'B' stands for block.

* p < 0.001 (2-tailed).

To assess cognitive load prior to pass completion, pupil size was analysed in each trial from the moment the ball was placed on the starting position to the moment participants directed their final gaze towards the target just before hitting the ball (time of interest). The mean pupil size was calculated for each hockey push-pass (in B1, B2, B3, B4, B5, B6), excluding the first trial of each block. The first trial of each block was excluded from analysis because the ball was already on the ground in position ready to hit.

Baseline correction considers the random fluctuations and individual differences in pupil size (Mathot et al., 2018). Therefore, change in the pupil size was our primary measure for cognitive load during the hockey push-pass tasks. To calculate change in the pupil size, we subtracted the mean baseline value from the mean pupil size in each block: Δ pupil size $_{\text{Block x}}$ = $M_{\text{Block x}}$ – Mean Baseline. Higher scores indicated higher changes in cognitive workload.

Performance accuracy. Performance was adjudged using 10 cm bandwidths radiating from the target, ranging from zero (i.e., hitting the target) to 16 (i.e., hitting 150-160 cm away from the target [outermost] interval). Consequently, a higher total score indicated lower hockey push-pass accuracy.

Bandwidth position was determined using manual frame-by-frame analysis of video recordings from the Tobii Pro Glasses 3 scene camera that was worn by participants during the experiment (1920 x 1080 pixels at 25 frames per second).

To be consistent with the pupillometry data analysis, we also excluded the first pass from every block of trials when analysing performance data. The median value was found for each block of hockey push-pass trials. The median was used instead of the mean for each block of trials to account for instances where the accuracy score of a pass was significantly higher or lower than the rest. Robustness to skewed data denotes the median as a better representation of the central tendency for accuracy of performance (Hughes et al., 2002; Lewis, 1993).

2.2.4 Data Analysis

Three (group: analogy, explicit, discovery) x 2 (time: pre-test, post-test) x 3 (task: single task 1, dual-task, single 2) repeated measures ANOVAs were used to examine changes in pupil sizes and performance accuracy. Significant effects were further investigated using follow-up ANOVAs or planned comparison pairwise t-tests with Bonferroni corrections where appropriate. Effect sizes were reported as partial eta squared. Statistical testing was performed in SPSS with the alpha level for all comparisons set to $p = 0.05$.

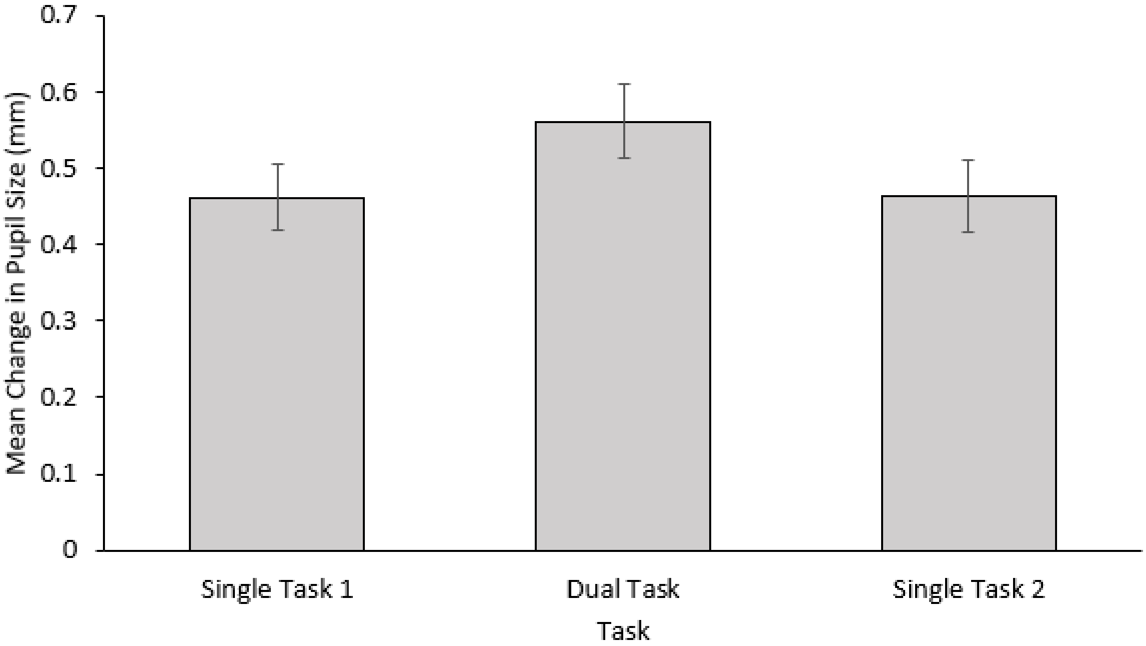
2.3 Results

2.3.1 Pupillometry Measures

A 3 (group: analogy, explicit, discovery) x 2 (time: pre-test, post-test) x 3 (task: single task 1, dual task, single task 2) repeated measures ANOVA revealed no significant main effects of time, $F(1, 12) = 0.001$, $p = 0.998$, $\eta_p^2 < 0.001$, or group, $F(1, 12) = 1.205$, $p = 0.334$, F(1, 12) = 1.205, p = 0.334, $\eta_p^2 = 0.167$. However, a significant main effect of task was evident for pupil dilation, $F(2, 24) = 7.311$, $p = 0.003$, $\eta_p^2 = 0.379$. Pupil dilation was greater during the dual tasks compared to the single tasks (see Figure 4). Bonferroni corrected planned comparisons (.05/3 = .017) showed that pupil dilation was not statistically greater during the dual task compared to single task 1, mean difference = 0.101, SE = 0.031, *p* = 0.019, 95% CI [0.016, 0.186], but was compared to single task 2, mean difference = 0.097, *SE* = 0.022, *p* = 0.003, 95% CI [0.035, 0.159]. No difference in pupil dilation was evident between single task 1 and single task 2, mean difference = 0.004, *SE* = 0.035, *p* = 1.000, 95% CI [-0.095, 0.102].

Figure 4

Mean Change in Pupil Size for Each Task with the Time and Group Variables Collapsed

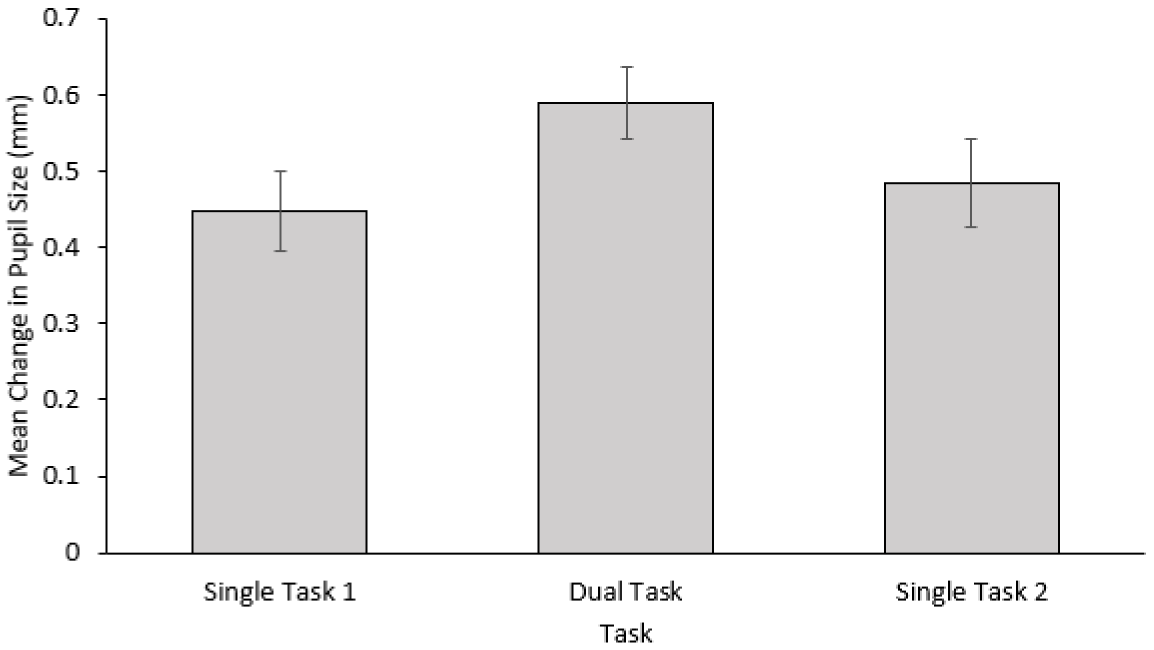


Note. Error bars represent the standard error of the mean. Pupil size measures are in millimetres.

The repeated measures ANOVA revealed a significant interaction between time and task, *F*(2,24) = 4.465, *p* = 0.024, η_p^2 = 0.267. One-way ANOVAs were therefore carried out to examine the pre-test and post-test separately. In the pre-test, a significant main effect of task on pupil dilation was found, *F*(2, 28) = 9.175, $p < 0.001$, η_p^2 = 0.396. Follow-up pairwise comparisons were performed, using a Bonferroni adjusted alpha level (.05/3 t-tests = .017). Participants displayed a greater increase in pupil size during the dual task compared to single task 1, mean difference = 0.143, *SE* = 0.033, *p* = 0.002, 95% CI [0.052, 0.233], and compared to single task 2, mean difference = 0.105, *SE* = 0.032, *p* = 0.017, 95% CI [0.018, 0.192] (see Figure 5).

Figure 5

Mean Change in Pupil Size for the Pre-Test Tasks with the Group Variable Collapsed

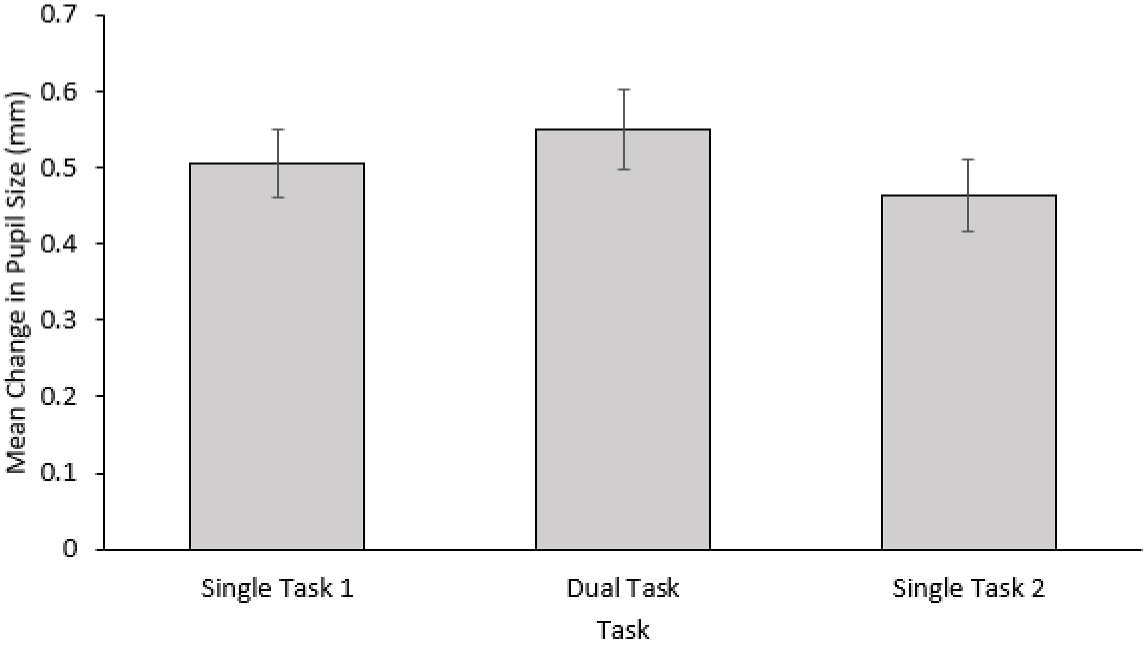


Note. Error bars represent the standard error of the mean. Pupil size measures are in millimetres.

In the post-test, the main effect of task approached significance, *F*(2, 28) = 3.094, *p* = 0.061, η_p^2 = 0.181. Given the effect size, Bonferroni corrected post-hoc comparisons were therefore conducted (.05/3 = .017). Pupil dilation was significantly greater during the dual task compared to single task 2, mean difference = 0.086, *SE* = 0.029, *p* =0.032, 95% CI [0.007, 0.165], but not single task 1 (see Figure 6).

Figure 6

Mean Change in Pupil Size for the Post-Test Tasks with the Group Variable Collapsed



Note. Error bars represent the standard error of the mean. Pupil size measures are in millimetres.

Significant interactions were not found between time and group, *F*(2, 12) = 0.042, *p* = 0.959, η_p^2 = 0.007, or between task and group, *F*(4, 24) = 0.739, *p* = 0.574, η_p^2 = 0.110. No significant three-way interaction was found, *F*(4, 24) = 1.628, *p* = 0.200, η_p^2 = 0.213.

2.3.2 Performance Data

A 3 (group: analogy, explicit, discovery) x 2 (time: pre-test, post-test) x 3 (task: single task 1, dual task, single task 2) repeated measures ANOVA was carried out to examine performance accuracy. There was no main effect of time, *F*(1, 13) = 1.694, *p* = 0.216, η_p^2 = 0.115, no main effect of task, *F*(2, 26) = 2.417, *p* = 0.109, η_p^2 = 0.157, and no main effect of group, *F*(1, 13) = 0.906, *p* = 0.428, η_p^2 = 0.122. We found no significant three-way interaction, *F*(4, 26) = 0.332, *p* = 0.854, η_p^2 = 0.049, no significant interaction between time and group, *F*(2, 13) = 0.040, *p* = 0.961, η_p^2 = 0.006, no significant interaction between task and group, *F*(4, 26) = 1.547, *p* = 0.218, $\eta_p^2 = 0.192$, and no significant interaction between time and task, *F*(2, 26) = 0.680, *p* = 0.515, $\eta_p^2 = 0.050$.

Chapter Three

Summary and Conclusion

3.1 Key Findings

It was hypothesized that there would be a significant increase in pupillometry measures (representative of cognitive load) for both the discovery and explicit groups in the post-test dual task compared to the post-test single tasks, while no significant change in pupil size was expected for the analogy group in the post-test dual task. No differences in pupil size were found between the groups in any of the tasks ($p > 0.05$).

It was also hypothesised that the pre-test dual task would cause a significant increase in cognitive load for all groups compared with the pre-test single tasks. This is because, for the dual task to be effective, novices should experience an elevated cognitive load when an additional task is introduced simultaneously. Follow-up comparisons showed a significant difference between pupil dilation in single task 1 and the dual task in the pre-test (Bonferroni corrected $p < 0.017$) but not the post-test (Bonferroni corrected $p > 0.017$). Follow-up comparisons also revealed that there was a significant difference between single task 2 and the dual task in both the pre-test (Bonferroni corrected $p < 0.017$) and post-test ($p < 0.05$).

In the post-test, a goal was to determine whether the dual task adversely impacted performance, following explicit instructions or no additional instructions for the discovery group. No differences in performance of the hockey push passes were evident in the study (p's > 0.05) indicating that the type of instruction did not impact motor performance of the task.

3.2 Discussion

The study delved into the influence of analogy learning on cognitive load and motor performance, emphasizing potential applications in sports settings. The objective was to gain insights into the effectiveness of analogies in learning environments and the utility of pupillometry as a measure of cognitive load during a motor task. The anticipation was that a noticeable shift in cognitive load would be observed from the pre-test to the post-test for the different learning conditions. This aligns with CLT, a framework that explores the mental effort and most efficient necessities for learning.

The outcomes of the experiment indicate some support for the validity of pupillometry as an indicator of cognitive load, evident in the variations in pupil size during dual tasks and single tasks. This is consistent with the finding that performing one task alone requires less mental effort than performing the same task in a dual task condition (Brünken et al., 2002; 2004).

In the post-test, cognitive load remained unchanged between single task 1 and the dual task, but it was significantly lower for single task 2 compared to the dual task. Single task 1 in the post-test involved the initial application of hockey push-passes after receiving either analogy, discovery, or explicit instructions. A plausible explanation for the observed similarity in cognitive load across all groups during the dual task and single task 1 in the post-test could be the ongoing processing of instructions. This aligns with findings reported by Chalkley (2021), where unexpected results indicated a significant increase in pupil dilation when participants were tasked with making a decision after watching a hockey scenario video. The post-instruction increases in cognitive load, as described by Chalkley (2021), could be attributed to participants still reflecting on the information given, potentially exploring alternative options. Furthermore, participants may have actively processed and experimented with the provided instructions to assess effectiveness for their individual performance, resulting in a higher cognitive load.

The hypothesis posited that the analogy group would display lesser changes in pupil sizes during the post-test dual task, as opposed to both the discovery and explicit groups. The concept was that a well-designed instructional approach, like an analogy, ought to be customized to the cognitive capacities of learners (Brünken et al., 2004). This customization ensures a smooth balance between intrinsic and extraneous cognitive loads, promoting optimal learning outcomes. Although a significant interaction was not found, trends in the bar graphs suggested that cognitive load measures remained relatively stable for the analogy group in the post-test for single task 1 (M = 0.61) and the dual task (M = 0.60). In contrast, the discovery group exhibited an increase in mean pupil size from single task 1 (M = 0.39) to the dual task (M = 0.47), while the explicit group also saw an increase from single task 1 (M = 0.48) to the dual task (M = 0.56). These findings, while intriguing, imply that with a larger participant pool, a significant interaction between the groups may have been observed. Consequently, we cannot definitively state that the analogy group demonstrated a lower cognitive load during the post-test dual task compared to the discovery and explicit groups. Remarkably, Fletcher et al. (2017) observed that heightened precision requirements in a task correlated with a decrease in pupil size during the execution of responses. Given that motor precision entails a necessity for heightened response accuracy, the imposition of more precise demands through discovery and explicit rules might be a possible explanation of the absence of increased pupil dilation during the task.

We also hypothesized that the performance accuracy in the post-test dual task condition would remain unaffected for the analogy group but would result in a decrease in performance for the discovery and explicit groups. Surprisingly, participants in none of the groups demonstrated differences in performance in the hockey-push pass task, contrary to our initial expectations. While we anticipated the analogy group to exhibit stable performance during the post-test dual task, we did not find any differences between groups. A possible explanation is that analogy instructions are less likely to impact motor-level learning; instead, their influence is expected to be on cognitive efficiency (van Duijn et al., 2019). Interestingly, Lam et al. (2009a; 2009b) found no significant differences in performance during retention tests between learners using analogy and explicit instructions in a basketball shooting task.

In contrast to the expectations derived from literature suggesting that analogies may exhibit increased resilience under a secondary task (Liao & Masters, 2001; Tse et al., 2016; 2017), potentially due to reduced cognitive system load, our study did not reveal significant differences in pupil dilation among the analogy, discovery, and explicit groups. This unanticipated outcome aligns with the findings from a study conducted by van Duijn et al. (2019), where EEG served as a measure of cognitive load. Their research demonstrated that individuals learning through analogies displayed more efficient cognitive processing, particularly in thinking and understanding. Interestingly, no significant differences were observed in cognitive activity during the planning of movement for the analogy learning group when compared with the explicit learning group.

Pupillometry's contribution as a measure of cognitive load in the context of hockey push-passes offers a unique insight into cognitive load during motor skill execution. Previously, subjective rating scales, GSR, and EEG have been the most utilised methods to measure cognitive load for a motor task. Pupillometry provides an advantage in a movement setting because it can allow us to specify a time of interest during the task being carried out.

3.3 Limitations and Future Research

To the best of the researchers' knowledge, this study represents the initial attempt to directly quantify cognitive load during the preparation phase of a motor skill. However, various limitations must be acknowledged within the current experiment.

The study heavily relied on pupillometry for cognitive load assessment, offering an overall indication. It is essential to note that while pupillometry offers a broad indication of cognitive load levels, it lacks the specificity to provide insights into particular areas of the brain. To gain deeper insights, future research should adopt a multimodal approach, integrating subjective measures and additional physiological indicators to provide a more nuanced understanding of cognitive processes during analogy-based learning (Chen et al. 2016).

It is worth considering the role of germane load, which pertains to cognitive resources dedicated to the acquisition of schema and deeper understanding (Sweller, 2010). Although germane load is not directly observable through pupillometry, its potential influence on cognitive efficiency and the learning process should be considered in future studies. If analogy learning does increase germane load while reducing extraneous load, its direct observation through pupillometry may be challenging, given its potential impact on cognitive efficiency and the learning process over time. The absence of a retention test in our study limits our understanding of the long-term retention of knowledge acquired through analogy-based learning. Future studies should incorporate retention assessments to evaluate the durability and transferability of skills over time.

It is also worth considering the role of heuristics, which could shape how individuals engage with analogy-based learning. Heuristics are mental shortcuts and biases that play a role in decision making and problem-solving (Tversky & Kahneman, 1974). Analogies are like heuristics in that they both help individuals make sense of information quickly. However, analogies aid the connection of distinct concepts for understanding whereas heuristics help provide cognitive shortcuts that may be useful for effective decision making or performance of a skill. Reliance on past heuristics may lead to variations in the efficacy of analogies. When heuristics facilitate the seamless accumulation of new information from an analogy, the process is simplified. However, if prior biases or oversimplifications exist, additional mental effort may be necessary to rectify or enhance understanding. This aligns with work done by Poolton et al. (2003) where a right-angled triangle analogy didn’t work for a Chinese-speaking population as it did for an English-speaking population. Meier et al. (2020) provided individualised analogies and explicit instructions to tennis players, resulting in improvements for participants in both groups. The absence of differences between the groups in our study suggested that individuals may have derived more benefits from diverse instructions tailored to their specific performance errors and learning preferences. Investigating the possible utilization of personalized analogies may yield advantages in future research, particularly when assessing cognitive load to determine potential distinctions between personalised and generalised analogies.

While acknowledging the constraint of a small participant pool in our study, it is noteworthy that meaningful main effects were still found through our analysis. Although the sample size posed challenges, the identified significant findings contribute valuable insights, encouraging a cautious yet meaningful interpretation of our study's outcomes.

While our findings provide valuable insights, the application of analogy-based learning in real-world coaching scenarios remains an area for exploration. Future research could delve into how coaches might effectively incorporate analogies into training sessions for enhanced skill acquisition and performance.

Emerging research suggests a connection between non-contact sports injuries and diminished cognitive function (Avedesian et al., 2022; Bertozzi et al., 2023; Chaaban et al., 2023; Gokeler et al., 2023; Lang et al., 2023). This raises interesting considerations for incorporating cognitive load measures, like pupillometry, into comparative studies that investigate situations involving divided attention across multiple sources. While introducing a secondary task in a coaching setting might present challenges, athletic environments naturally feature numerous distractions. In a typical sports environment, it could be advantageous to utilize measures of cognitive load, if feasible, by leveraging the inherent distractions encountered.

3.4 Conclusion

This study underscores the potential of pupillometry as a valuable tool for assessing cognitive load in motor tasks and exploring various implicit motor learning modes. However, addressing the identified limitations is imperative for the widespread adoption of our approach. These findings contribute to the broader understanding of analogy-based learning in sports and educational contexts. Further research and refinement are necessary to overcome limitations, ensuring the applicability and effectiveness of our approach on a larger scale. The ongoing importance of research in this domain is emphasized to enhance the impact of analogy-based learning in diverse settings. As the saying goes, "the eyes are the windows to the soul," pupillometry may provide us with profound insights into sport science, offering a unique understanding of various aspects through the examination of pupil responses.

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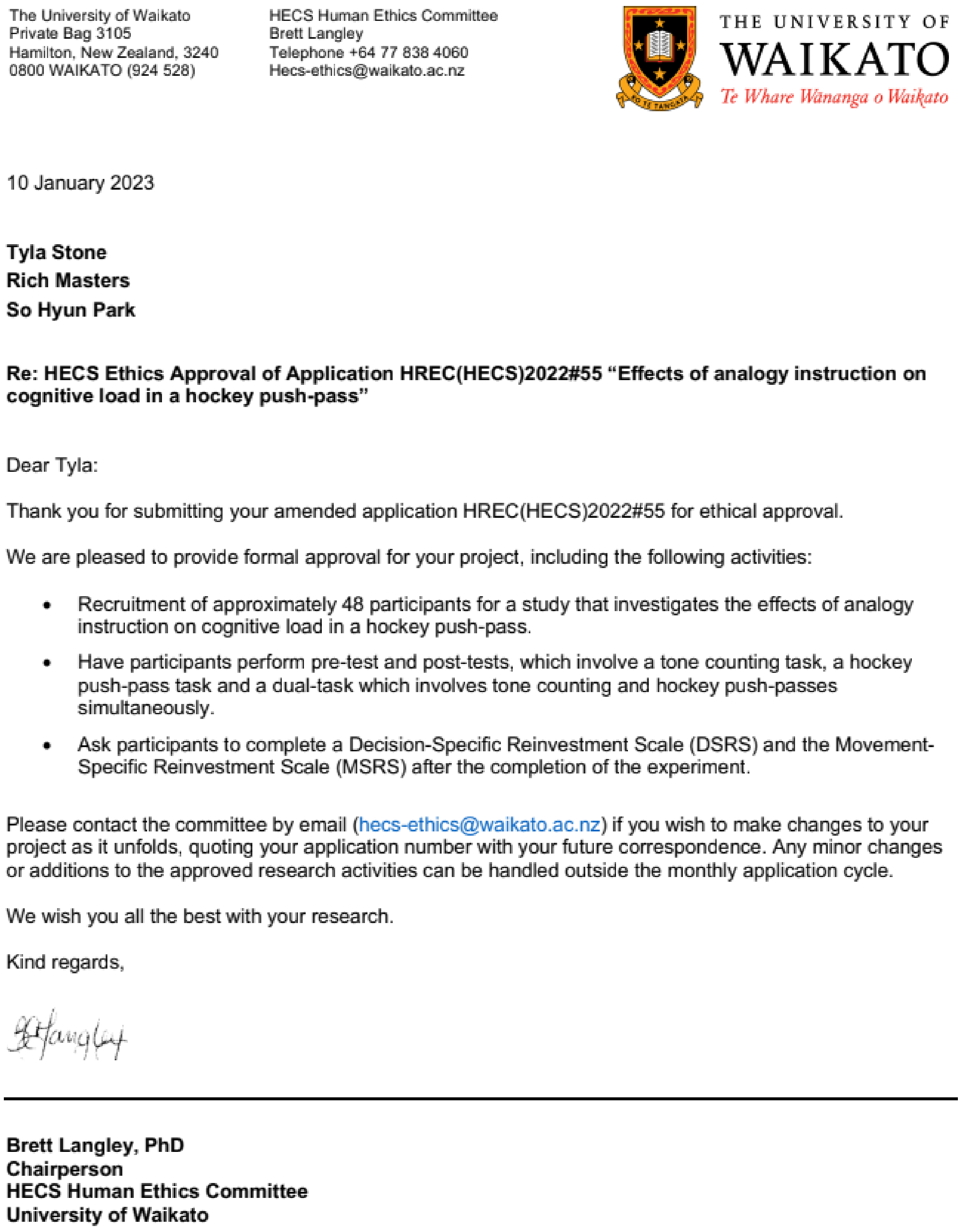
Appendices

Appendix 1 – Ethics Approval



The University of Waikato
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Hamilton, New Zealand, 3240
0800 WAIKATO (924 528)

HECS Human Ethics Committee
Brett Langley
Telephone +64 77 838 4060
Hecs-ethics@waikato.ac.nz

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

10 January 2023

Tyla Stone
Rich Masters
So Hyun Park

Re: HECS Ethics Approval of Application HREC(HECS)2022#55 "Effects of analogy instruction on cognitive load in a hockey push-pass"

Dear Tyla:

Thank you for submitting your amended application HREC(HECS)2022#55 for ethical approval.

We are pleased to provide formal approval for your project, including the following activities:

- Recruitment of approximately 48 participants for a study that investigates the effects of analogy instruction on cognitive load in a hockey push-pass.
- Have participants perform pre-test and post-tests, which involve a tone counting task, a hockey push-pass task and a dual-task which involves tone counting and hockey push-passes simultaneously.
- Ask participants to complete a Decision-Specific Reinvestment Scale (DSRS) and the Movement-Specific Reinvestment Scale (MSRS) after the completion of the experiment.

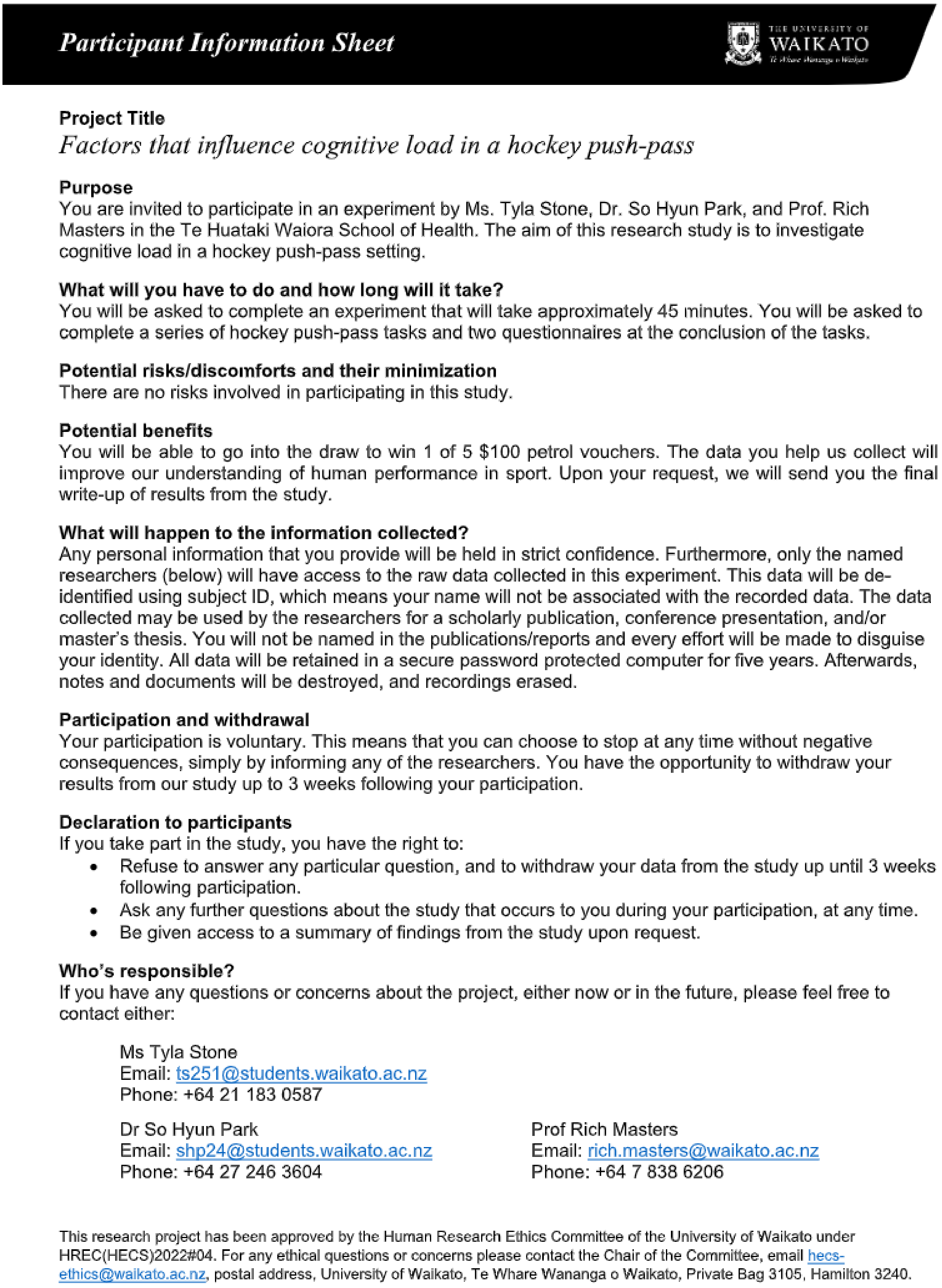
Please contact the committee by email (hecs-ethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Kind regards,

Brett Langley, PhD
Chairperson
HECS Human Ethics Committee
University of Waikato

Appendix 2 – Participant Information Form



Participant Information Sheet

Project Title

Factors that influence cognitive load in a hockey push-pass

Purpose

You are invited to participate in an experiment by Ms. Tyla Stone, Dr. So Hyun Park, and Prof. Rich Masters in the Te Huataki Waiora School of Health. The aim of this research study is to investigate cognitive load in a hockey push-pass setting.

What will you have to do and how long will it take?

You will be asked to complete an experiment that will take approximately 45 minutes. You will be asked to complete a series of hockey push-pass tasks and two questionnaires at the conclusion of the tasks.

Potential risks/discomforts and their minimization

There are no risks involved in participating in this study.

Potential benefits

You will be able to go into the draw to win 1 of 5 $100 petrol vouchers. The data you help us collect will improve our understanding of human performance in sport. Upon your request, we will send you the final write-up of results from the study.

What will happen to the information collected?

Any personal information that you provide will be held in strict confidence. Furthermore, only the named researchers (below) will have access to the raw data collected in this experiment. This data will be de-identified using subject ID, which means your name will not be associated with the recorded data. The data collected may be used by the researchers for a scholarly publication, conference presentation, and/or master's thesis. You will not be named in the publications/reports and every effort will be made to disguise your identity. All data will be retained in a secure password protected computer for five years. Afterwards, notes and documents will be destroyed, and recordings erased.

Participation and withdrawal

Your participation is voluntary. This means that you can choose to stop at any time without negative consequences, simply by informing any of the researchers. You have the opportunity to withdraw your results from our study up to 3 weeks following your participation.

Declaration to participants

If you take part in the study, you have the right to:

- Refuse to answer any particular question, and to withdraw your data from the study up until 3 weeks following participation.
- Ask any further questions about the study that occurs to you during your participation, at any time.
- Be given access to a summary of findings from the study upon request.

Who's responsible?

If you have any questions or concerns about the project, either now or in the future, please feel free to contact either:

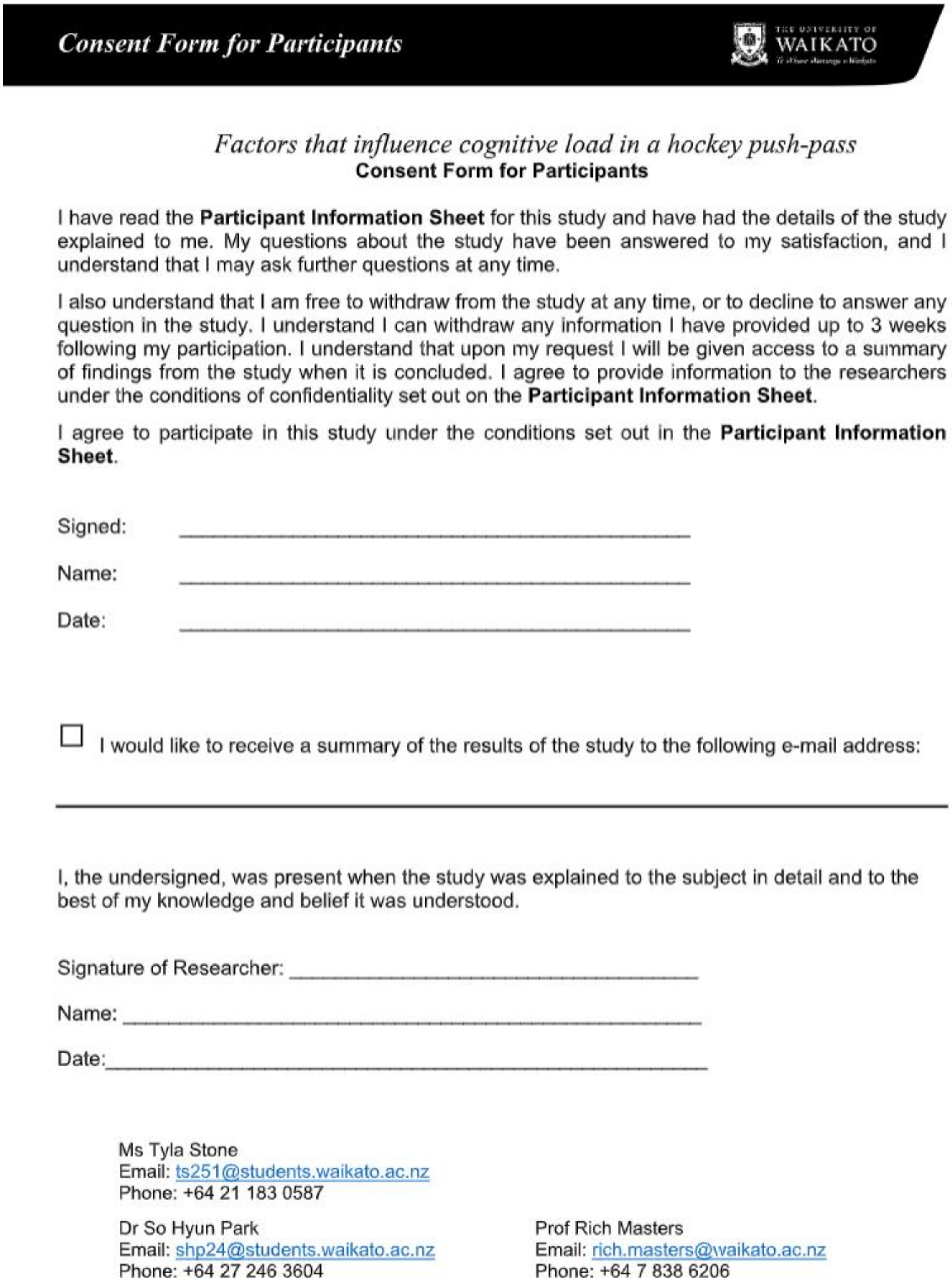
Ms Tyla Stone
Email: ts251@students.waikato.ac.nz
Phone: +64 21 183 0587

Dr So Hyun Park
Email: shp24@students.waikato.ac.nz
Phone: +64 27 246 3604

Prof Rich Masters
Email: rich.masters@waikato.ac.nz
Phone: +64 7 838 6206

This research project has been approved by the Human Research Ethics Committee of the University of Waikato under HREC(HECS)2022#04. For any ethical questions or concerns please contact the Chair of the Committee, email hecs-ethics@waikato.ac.nz, postal address, University of Waikato, Te Whare Wananga o Waikato, Private Bag 3105, Hamilton 3240.

Appendix 3 – Participant Consent Form



Consent Form for Participants

THE UNIVERSITY OF WAIKATO

Factors that influence cognitive load in a hockey push-pass

Consent Form for Participants

I have read the **Participant Information Sheet** for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw from the study at any time, or to decline to answer any question in the study. I understand I can withdraw any information I have provided up to 3 weeks following my participation. I understand that upon my request I will be given access to a summary of findings from the study when it is concluded. I agree to provide information to the researchers under the conditions of confidentiality set out on the **Participant Information Sheet**.

I agree to participate in this study under the conditions set out in the **Participant Information Sheet**.

Signed: ____________________

Name: ____________________

Date: ____________________

☐ I would like to receive a summary of the results of the study to the following e-mail address:

____

I, the undersigned, was present when the study was explained to the subject in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ____________________

Name: ____________________

Date: ____________________

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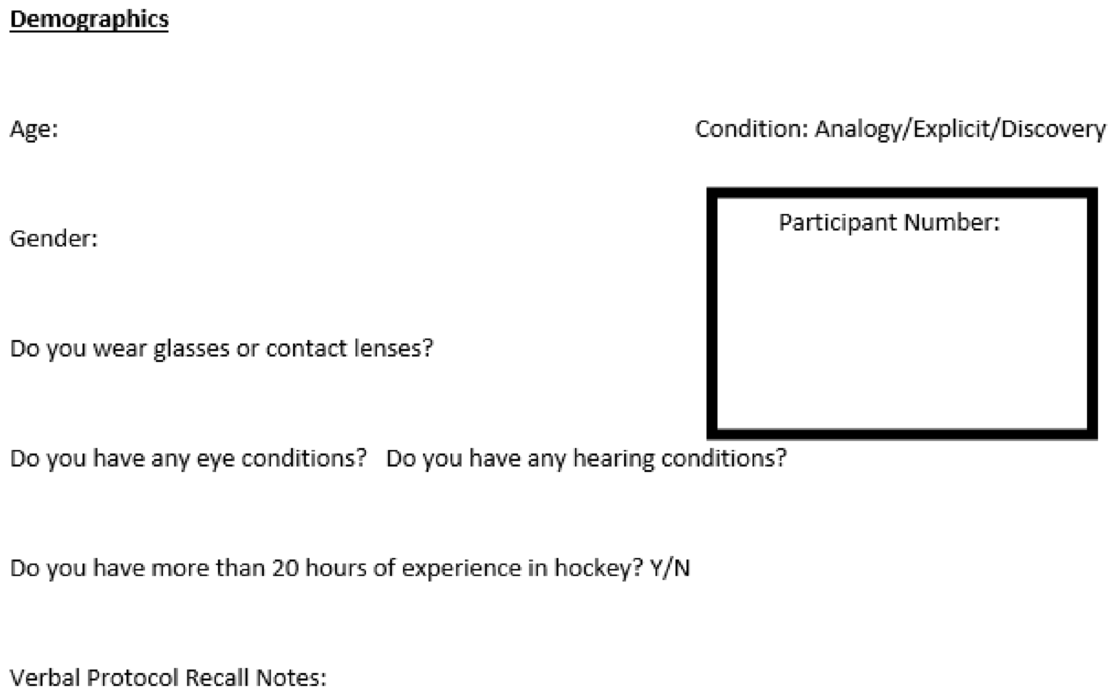
Appendix 4 – Verbal Protocal Recall and Demographics Sheet



Demographics

Age:

Condition: Analogy/Explicit/Discovery

Gender:

Participant Number:

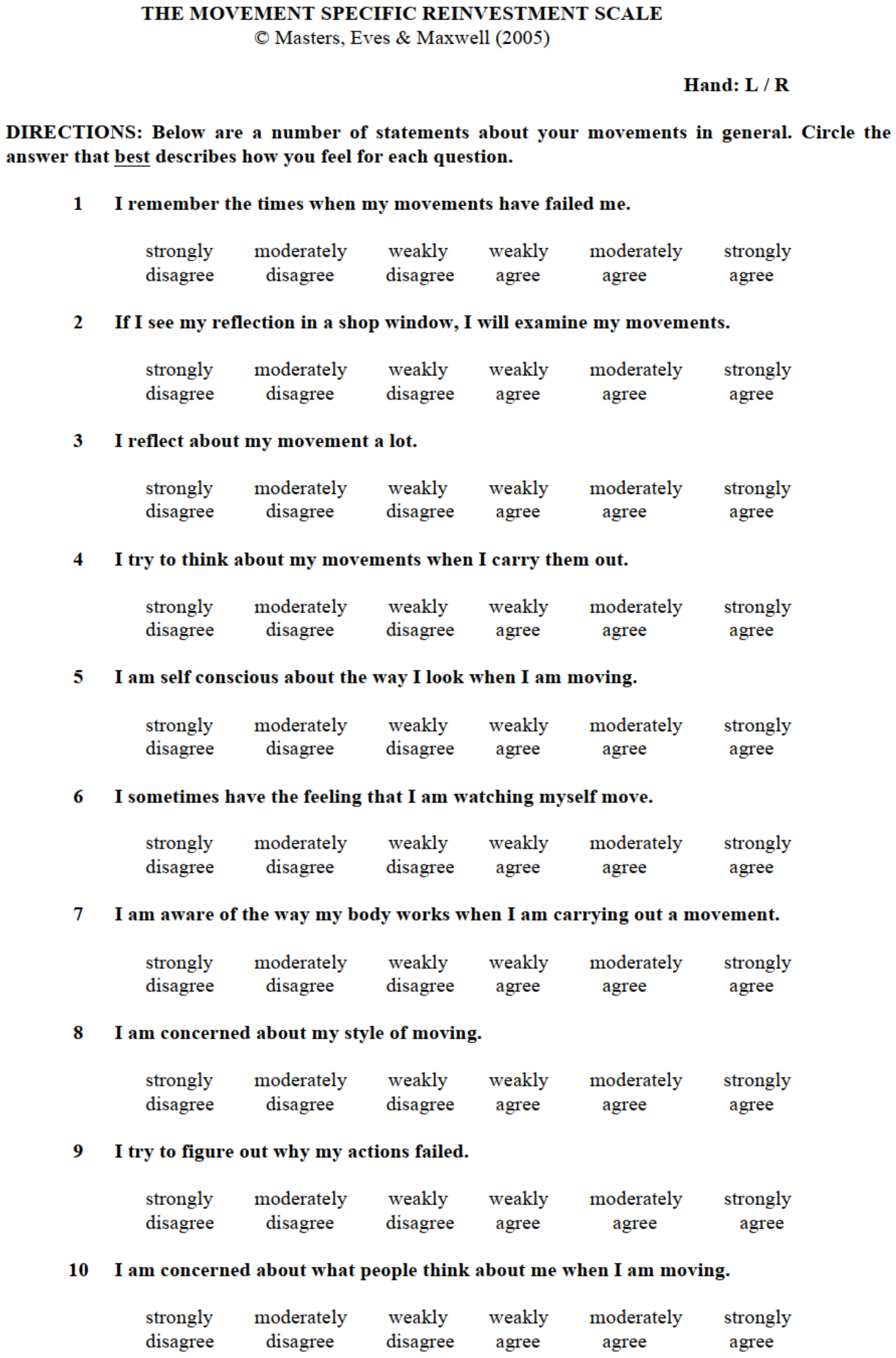
Do you wear glasses or contact lenses?

Do you have any eye conditions? Do you have any hearing conditions?

Do you have more than 20 hours of experience in hockey? Y/N

Verbal Protocol Recall Notes:

Appendix 5 – Movement Specific Reinvestment Scale (MSRS) and Scoring



THE MOVEMENT SPECIFIC REINVESTMENT SCALE

© Masters, Eves & Maxwell (2005)

Hand: L / R

DIRECTIONS: Below are a number of statements about your movements in general. Circle the answer that best describes how you feel for each question.

1 I remember the times when my movements have failed me.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

2 If I see my reflection in a shop window, I will examine my movements.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

3 I reflect about my movement a lot.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

4 I try to think about my movements when I carry them out.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

5 I am self conscious about the way I look when I am moving.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

6 I sometimes have the feeling that I am watching myself move.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

7 I am aware of the way my body works when I am carrying out a movement.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

8 I am concerned about my style of moving.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

9 I try to figure out why my actions failed.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

10 I am concerned about what people think about me when I am moving.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree

SCALE SCORING - Movement Specific Reinvestment Scale (MSRS)

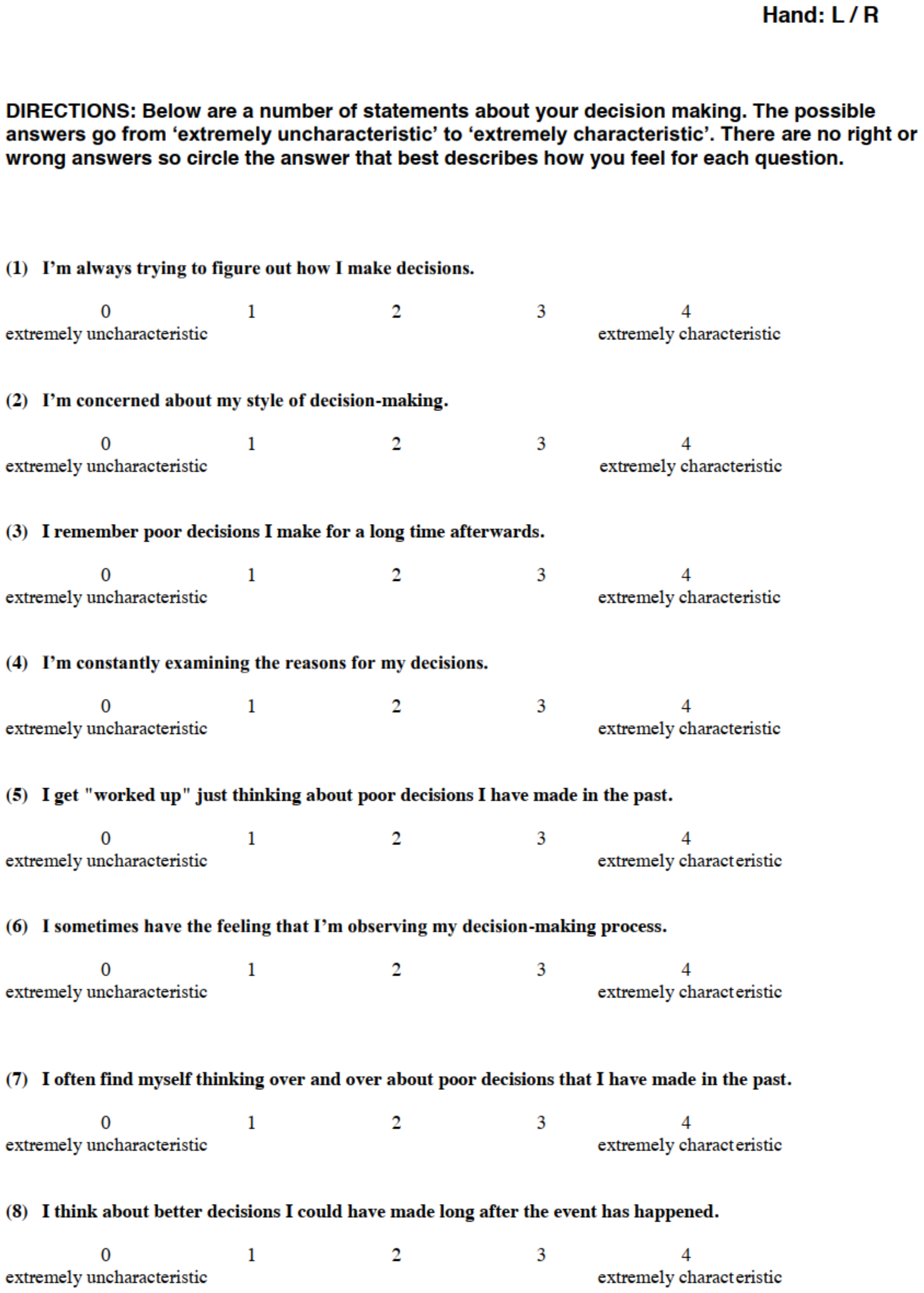
We developed the MSRS to be more specific to movement. Scoring is as follows:

Factor 1 (Movement Self-consciousness) = items 2, 5, 6, 8, 10
The composition of items that cluster in this factor suggests concern about moving in public. High scores on the factor indicate people who are aware of themselves as social objects, and who worry about their 'style' of movement and about making a good impression when they move.

Factor 2 (Conscious Motor Processing) = items 1, 3, 4, 7, 9
These items suggest contemplation of the process of movement, as reflected in past, present and future motor activity. Individuals who score highly on this factor are likely to monitor the mechanics of their movements in the way that the Theory of Reinvestment suggests.

Each item is scored from 1 point (strongly disagree) up to 6 points (strongly agree), so the maximum score on each factor is 30. No items are reverse scored.

Appendix 6 – Decision Specific Reinvestment Scale (DSRS) and Scoring



Hand: L / R

DIRECTIONS: Below are a number of statements about your decision making. The possible answers go from 'extremely uncharacteristic' to 'extremely characteristic'. There are no right or wrong answers so circle the answer that best describes how you feel for each question.

(1) I'm always trying to figure out how I make decisions.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(2) I'm concerned about my style of decision-making.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(3) I remember poor decisions I make for a long time afterwards.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(4) I'm constantly examining the reasons for my decisions.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(5) I get "worked up" just thinking about poor decisions I have made in the past.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(6) I sometimes have the feeling that I'm observing my decision-making process.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(7) I often find myself thinking over and over about poor decisions that I have made in the past.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(8) I think about better decisions I could have made long after the event has happened.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(9) I am alert to changes in how much thought I give to my decisions.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(10) I'm aware of the way my mind works when I make a decision.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(11) I rarely forget the times when I have made a bad decision, even about the minor things.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(12) When I am reminded about poor decisions I have made in the past, I feel as if they are happening all over again.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

(13) I'm concerned about what other people think of the decisions I make.

0	1	2	3	4
extremely uncharacteristic				extremely characteristic

Scoring for Decision Reinvestment Scale

Factor 1: Decision reinvestment

Items: 1, 2, 4, 6, 9, 10

Minimum score 0 – maximum score 30

Factor 1: Decision Rumination

Items: 3, 5, 7, 8, 11, 12, 13

Minimum score 0 – maximum score 35