THE SPECIFICITY AND GENERALIZABILITY OF MOTOR LEARNING

THE SPECIFICITY AND/OR GENERALIZABILITY OF MOTOR LEARNING: A SCOPING REVIEW, A CHECKLIST, AND A FRAMEWORK FORWARD

By

Claire Marie Tuckey, BPhEd, MSc

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TITLE: The Specificity and/or Generalizability of Motor Learning: A Scoping Review, a Checklist, and a Framework Forward

AUTHOR: Claire Marie Tuckey, BPhEd, MSc

SUPERVISOR: Jim Lyons, PhD

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LAY ABSTRACT

Our previous movement experiences can impact our capability to learn new motor tasks. These previous movement experiences can be either beneficial or detrimental (or have no effect) on our learning of that task depending on many different things with no real definitive answers to why the outcomes differ and when. The purpose of this thesis is to review how prior motor skill practice may be beneficial to future motor skill learning (generalizability), detrimental to learning, or no effect (specificity) and to organize these findings into a new ‘types of transfer’ taxonomy, create a framework to help guide future motor learning research and conduct an experiment that follows this framework. By considering and organizing this large motor learning literature into a review, creating this taxonomy and outlining an empirical investigative framework, this thesis will help us to better understand motor learning history and provide a pathway forward for future researchers.

ABSTRACT

Humans are constantly faced with learning motor tasks throughout their lifespan (e.g., children learning how to throw a ball overhand, elite athletes learning how to become more even more efficient at their sports performance, and an older adult relearning how to walk post-stroke recovery). With such variety in the types of motor tasks that humans try to learn across the lifespan, little is known about the impact of a learner's previous motor skill experience. Thus, the purpose of this thesis was to investigate when motor learning generalizability or specificity are more likely to occur, respectively. An in-depth background of motor learning generalizability and specificity was provided in chapter one. The scope of the motor learning literature including generalizability and/or specificity was investigated in chapter two. At the end of chapter two, certain limitations of the motor learning literature are addressed and framed into a useable checklist for future motor learning experiments. Chapter three serves as a bridging chapter to connect the scoping review and checklist in chapter two, to the framework implemented in chapter four. In chapter four, the checklist was employed to assess its usefulness in future motor learning experiments. Collectively, this thesis provides organization to the previous motor learning generalizability and specificity literature, as well as recommendations for future motor learning researchers based on a tested framework protocol.

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LIST OF ABBREVIATIONS

VR	Virtual reality
KP	Knowledge of performance
KR	Knowledge of results
TOTE	Test-operate-test-exit
CINAHL	Cumulated index to nursing and allied health literature
QCRI	Qatar Computing Research Institute
PRISMA	Preferred reporting items for systematic review and meta-analyses

NSERC	Natural Sciences and Engineering Research Council of Canada
EV	Ecological validity
CP	Conditions of practice
AN	Anthropometrical
EQ	Equipment
EX	Expertise
FB	Feedback modality
MI	Attention
TT	Target/Task
ST	State
VE	Virtual environment
MT	Movement time
AE	Absolute error
CE	Constant error
VE	Variable error
RMSE	Root mean square error
RT	Reaction time
COM	Center of mass
EMG	Electromyography
CI	Contextual interference
FLS	Fundamentals of Laparoscopic Surgery
VBLaST	Virtual Basic Laparoscopic Skill Trainer

PD	Parkinson’s disease
Ex. 1	Experiment one
Ex. 2	Experiment two
CSR	Choice stimulus-response
ACE	Absolute constant error
ABSE	Absolute error of relative phase
BDNF	Brain-derived neurotrophic factor
M	Mean
SD	Standard deviation
SEM	Standard error of the mean
MREB	McMaster Research Ethics Board
MVC	Maximum voluntary contraction
COVID-19	Coronavirus disease 2019
ANOVA	Analysis of variance
EA	Early acquisition
IR	Immediate retention
DR	Delayed retention
T	Transfer
HSD	Honestly significant difference
ms	milliseconds

GLOSSARY

Term	**Operational Definition**
Acquisition	The initial or early-stage practice or performance of a new or novel motor skill. May also refer to the practice of a new type of movement control for a previously learned motor skill.
Retention	The preservation of a movement skill after a period of rest where no overt practice of the skill takes place.
Transfer	The attempt to apply a learned skill in a new task or context. At this time, there are no parameters to neither which elements of the skill are changed, nor the magnitude to which the skill is changed. Transfer can include attempting an entirely new task, on the premise that previous experience on another task will be applied. The term 'transfer' does not indicate the success level of the application to the new task.
Generalizability	The ability to apply what has been learned in one context to other contexts with motor performance success. This refers to a positive gain from a previous motor task to the transfer of a new motor task.
Specificity of Practice	A principle that rationalizes how some motor skills are very specific and uncorrelated with one another and leaves the learner with motor skills that are not generalizable. This refers to a negative

	decrement from a previous motor task to the transfer of a new motor task.
Motor Learning	Changes in an organism's movements that reflect changes in the structure and function of the nervous system. This is a process that demonstrates a relatively permanent change in the ability to execute a motor skill as a result of practice or experience.
Motor Adaptation	The process of acquiring and restoring movement patterns through an error-driven learning process.
Motor Development	The change in motor behaviour over the life span, and the sequential, continuous, age-related process of change.
Ecological Perspective	In an attempt to generalize a motor skill, an ecological perspective is not limited to 'real world' transfer tasks. An ecologically valid transfer task replicates an environment, setting, or conditions to better make inferences towards its generalizability.
Affordances	As described by (Gibson, 1979), affordances define objects as a fact of the environment as well as a fact of behaviour. Sensorimotor capabilities of the individual constrain the kind of information that is accessed regarding an object and the meanings associated with it.
Virtual Reality (VR)	An artificially created environment typically consisting of computer-generated information made available to the human sensory systems (e.g., visual, auditory, tactile, etc.) that appear to

be “real”. The effect is to make the user experience sensory immersion in their surroundings.

DECLARATION OF ACADEMIC ACHIEVEMENT

I, Claire Tuckey, declare this thesis to be my own work. I am the sole author of this document. No part of this work has been published or submitted for publication for a degree at another institution.

To the best of my knowledge, this work does not infringe on anyone's copyright.

My supervisor, Dr. Jim Lyons, and the members of my supervisory committee, Dr. Michael Carter, Dr. Lawrence Grierson, and Dr. Lori Ann Vallis, have provided feedback and guidance at all stages of this thesis. My secondary readers provided feedback on titles and abstracts per scoping review procedures, and McMaster Health Sciences librarians provided support through the creation of the scoping review search trains across search engines. I completed all of the research work.

CHAPTER 1: GENERAL INTRODUCTION TO THE HISTORICAL PERSPECTIVES OF MOTOR LEARNING

1.1 General Introduction

Learning is fundamental to humans at every developmental level. The first evidence of learning as a concept dates back to Ancient Greece and the perspectives of the early philosophers. At this time, how knowledge comes to humans was divided into two general ideas: rationalism and empiricism. Rationalism suggests that knowledge comes from an innate place and may happen without external stimuli. Conversely, empiricism relates to knowledge coming from experience and does not exist without external stimuli. Learning has been researched for hundreds of years, yet its definitions are still evolving. The definition of learning has evolved and one of the more recent definitions for learning is “the process by which relatively stable modification in stimulus-response relations is developed as a consequence of functional environmental interaction via the senses” (Lachman, 1997, p. 477). This definition distinguishes learning from other phenomena such as sensory adaptation, and the effects of maturation. To fully understand motor skill learning, it is important to acknowledge its connection to the broader field of learning. Within this broader field of learning, motor skill learning isolates any learning wherein goal-directed, usually observable, movements or actions are performed by the motor system. While much is known and understood about motor skill learning, and how new skills can be acquired and retained, there are still gaps in the literature relating to broader concepts of which motor skills are generalizable, and those which motor skills may be specific to the context in which they have been practiced. One of the greatest challenges with understanding motor learning is the breadth of the topic itself, making the creation of new definitions and new ways to organize the literature difficult. This thesis, therefore, provides an extensive examination of the generalizability and specificity of motor skill learning. In this research, I intend to determine the extent to which motor skill learning can be generalizable or specific and to formalize an organizational solution to the breadth of research included in this literature. This thesis is composed of five themed chapters. The first chapter provided an overview of motor learning and the key concepts and theories that will be used in subsequent chapters. Chapter two will assess the scope of all motor learning literature with motor skill generalizability or specificity with an attempt to find commonalities between them as well as presenting a taxonomy to organize the motor learning generalizability and specificity literature, and a checklist to aid in overcoming common methodological limitations identified in the motor learning literature. Chapter three bridges the main outcomes of chapter two and explains how they will be implemented into an investigative framework in chapter four. Chapter four builds on the results and discussions of the prior three chapters by reporting a protocol, developed as a proof of concept, for an experiment to demonstrate the most salient form of specificity of motor learning. Chapter five focuses on a discussion of the main points of this thesis relating to motor skill generalizability, motor skill specificity, a taxonomy to use in future motor skill learning research, and the protocol design presented to prove a concept for salient specificity of learning results.

1.2 Defining Motor Learning

1.2.1 Motor Adaptation vs. Motor Development vs. Motor Learning

Motor adaptation, motor development, and motor learning share a commonality; changes in the way individuals move over time (Newell et al., 2001). While the focus of this thesis is on motor learning, this term is interrelated with motor adaptation and motor development thus requiring some clarification as to how these definitions coincide and how they differ. From a human evolutionary perspective, motor adaptation exists as a means of survival and ecological fitness of the sensorimotor system (Babič et al., 2016).

Motor adaptation refers to the trial-and-error process of adjusting movements to new demands and involves predictive calibrations associated with new task demands (Bastian, 2008). Adaptations are made to help minimize movement 'costs' associated with energy demands, fatigue, and movement inefficiencies (Bastian, 2008). Repeated adaptations can lead to learning a new motor calibration (Bastian, 2008).

Motor development is a term used to describe the changes in motor behaviours that occur throughout a human life span. Motor development reflects humans' interactions among the maturing organism, the environment, and the task (Newell, 1986). One influential explanation of this developmental process is Newell's model of constraints (1986) which describes an evolving three-way interaction of systems among the individual, the environment and the task, which results in the movements of which humans are capable at any given point across the lifespan. Furthermore, each of these factors is characterized as a 'constraint' that can impact movement outcomes. The individual system constraints can be further subdivided into functional or structural constraints. A functional constraint relates to the behaviour of the individual (e.g., fear, motivation, attentional focus). A structural constraint relates to the individual's anatomical structure that changes as people grow or age (e.g., height, weight, strength). Environmental system constraints are external to the body and involve the world around each person (e.g., temperature, floor surfaces, humidity). Lastly, the task system constraints relate to the goals and rules involved in the motor activity (e.g., in basketball, it would be faster to run carrying the ball, but the rules state that you must dribble the ball). Movement is a product of the constraints constantly interacting and modifying one another based on the moment-to-moment demands of the task (Garcia & Garcia, 2006).

Motor learning, as a general concept, is a complex phenomenon involving both motor adaptation and motor development. Motor learning is generally defined as a relatively permanent and stable gain in motor skill capability that is associated with practice or experience (e.g., Adams, 1964; Fitts, 1964; Newell & Rosenbloom, 1982). According to this definition, practice is fundamental for motor learning to occur and, without practice, the action would be a cross-sectional display of in-the-moment motor performance (see Section 1.2 for a more detailed delineation of the differences between motor learning and motor performance). Skill capability refers to the potential of an individual, which can be developed with practice, but depends on the presence of a subset of abilities (Nagarajan & Prabhu, 2015). Take, for example, the skill of successfully flipping a pancake in a frying pan without using a spatula. This requires both ability (e.g., the dexterity to grasp the handle of the pan and the forearm strength to hold the frying pan) and capability (i.e., the wrist motion to successfully flip the pancake that can be learned with practice). Motor learning also involves a set of processes aimed at learning and refining new skills through practice (Nieuwboer et al., 2009).

1.3 Classifications of Movements, Actions, and Skills

1.3.1 Fine vs. Gross Motor Skills

In any discussion of motor skill learning, it is important to note that not all motor skills, or the movements that provide the foundation for those skills, are “created equal”. In other words, the term motor skill as a catch-all phrase implies a misleading homogeneity to complex situations. Indeed, how motor skills are learned, and how successful the practice conditions are in the acquisition of those skills, can vary greatly depending on how the skilled movements are classified. Therefore, how movements, actions, and skills are classified is important for the generalizations we can, and cannot, make about them. Motor skills can generally be classified on a continuum from fine to gross (Davis, 2000). Fine motor skills involve smaller muscles and can be used for more precision movements (e.g., writing, grasping), whereas gross motor skills involve skills containing larger muscle groups required for movements. Gross motor skills can be further categorized into locomotor activities (e.g., walking, running, hopping, skipping), non-locomotor activities (e.g., bending, stretching, twisting, turning), and manipulative skills (e.g., throwing, kicking, striking, catching).

1.3.2 Continuous vs. Discrete vs. Serial Motor Skills

Another way to classify movements, actions, and skills is through how the motor task is sequenced. The sequence of a motor skill can fall on a continuum, with one end representing discrete skills that have a clear start and end. These skills can be repeated, but the performer would essentially be starting over each time (an example of a discrete skill is a vertical jump, Davis, 2000). A serial motor task is in the middle of this continuum and is composed of several discrete motor tasks being strung together to create an integrated movement (e.g., a triple jump including the hop, skip, and jump phases) (Davis, 2000). On the other end of the continuum are continuous skills, with no obvious start or endpoints, and could be performed in theory for as long as the individual wishes (e.g., walking, running, Davis, 2000). Understanding the classification of a motor skill in terms of being continuous, discrete, or serial is important for measuring the motor task. A researcher/coach/teacher will need to know how to identify the start and end of a movement, from one movement to the next. To simplify the motor task being examined, motor learning researchers will often use discrete motor tasks to initially test their research question for this reason of clear measurements. Discrete skills are generally a rapid task with little time to apply intrinsic feedback corrections during the movement. When motor tasks are carried out over a longer period of time as in a more continuous task, then feedback can be used throughout the task to monitor and correct movements. For example, tracking tasks, such as a rotary pursuit, would be considered a continuous task and would be a closed-loop control as it can be monitored via sensory feedback (Schmidt & Wrisberg, 2008). These are all important factors in motor learning that change the dynamics of not only the duration of the task, and musculature used in the task but also the sensory information that is involved.

1.3.3 Open vs. Closed Environments

The ability of an individual to complete a movement depends on the context of the environment around them. Closed environments refer to a stationary environmental context, and open environments refer to complex and non-regulatory events in the external environment. With these binary labels, it is important to note that within a "closed" environment context, an individual is still free to execute a variety of movements. An open motor environment has a variable and unpredictable setting, where the performer cannot evaluate all the environmental demands or fully prepare their motor actions in advance. In between predictable (closed) (e.g., typing on a keyboard) and unpredictable (open) (e.g., playing whack-a-mole) motor skills, there can be semi-predictable environments (e.g., playing chess). In the typing on a keyboard example, the keys on the keyboard never change, creating a predictable environment for the individual typing. In the playing whack-a-mole example, the player cannot plan their next move. Their movements that take place depend on the environment. The chess example is a semi-predictable environment where there are a limited number of options available to an opponent to move, allowing the player to plan with some movement possibilities.

1.3.3.1 Open vs. Closed Motor Skills

Open and closed motor skills differ from open and closed environments. An open environment can make a typically closed motor skill more challenging to perform. For example, swinging a baseball bat to hit a ball off a tee in a non-competitive nature is a closed motor skill in a closed environment. The batter can choose when they swing the bat, and there is certainty about the ball's location. The same motor skill can be placed in an open environment in a game scenario with opponents. Now the batter needs to strategize where to hit the ball depending on fielder locations and other base runners. The context of the environment can change whether the motor skill is open or closed. These open and closed motor skills fit on a continuum rather than as a binary. Preparing for a ball that is thrown from a pitcher on the opposing team is a more challenging task compared to hitting the ball off of a tee in a baseball game, making the former a more open environmental task than the latter.

1.4 The Performance-Learning Distinction

From a philosophical perspective, it has been stated that "No one has ever measured learning or memory. They can be only inferred from behavior." (Cahill et al., 2001, p. 578). Motor learning cannot be confirmed from a single quantitative measure, but rather behavioural tests that allow for logical inferences based on the comparison of prior behaviours. To make any inferences as to whether motor learning has occurred, retention and transfer tasks can be used to assess motor skill performance after a period and under a common context. Retention tests assess the learner's performance of the same skill from acquisition following a period of time where no overt practice on that skill has taken place. The purpose of the retention task is to evaluate the extent to which the skill has been retained by the learner. Retention tasks call on the individual to reproduce later what they've previously acquired. A transfer task, in comparison, is designed to test the learner on a new variation of the skill, a different testing situation, or context with the intention to test the generalizability of what was acquired during practice (Kantak & Winstein, 2012).

An important consideration when implementing retention and transfer tasks is the timing of when they are executed after the acquisition period. Kantak and Winstein (2012) reviewed motor learning studies that have both immediate (from 10 seconds to a couple of hours) and delayed (24 hours or more) retention/transfer tests. Observations from Kantak and Winstein (2012) suggest that in at least 63% of the studies included in their review, motor performance in an immediate retention/transfer test was not a good predictor of relatively permanent motor learning. This review by Kantak and Winstein (2012) provides evidence in support of the learning-performance distinction and supports utilizing a delayed retention/transfer test of at least 24 hours after the acquisition as a more reflective measure of the relative permanence of motor learning.

1.4.1 The Power Law of Practice

Across many motor tasks, there will be a stereotypical pattern of performance, which can be described by a graphed curve, represented by an initially steep motor acquisition period, followed by a plateau of performance. Snoddy (1926) was the first to formalize the observation that the rate of improvement in the performance of a motor task can be characterized by a power function. This "power law of practice" states that: 1) the time it takes to perform a task decreases with the number of repetitions of that task, and 2) the decrease follows the shape of the power law (See Figure 1.1).

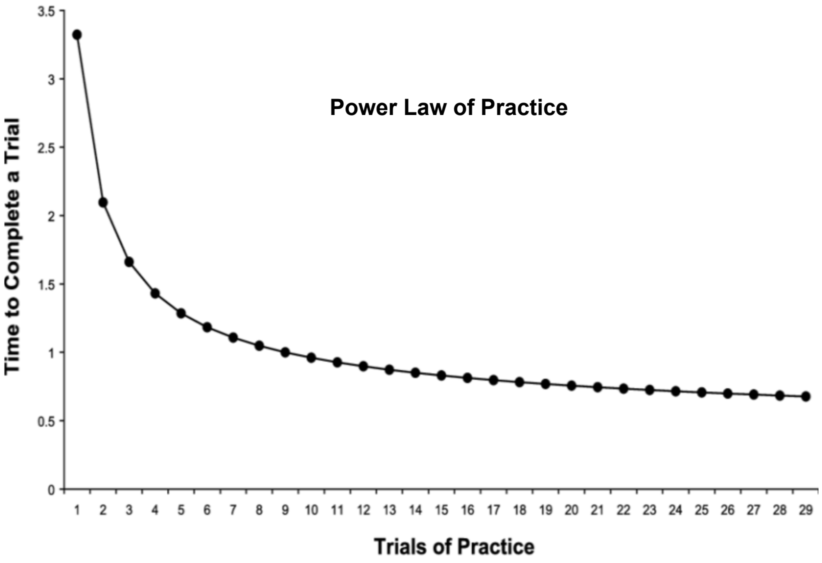


Figure 1.1: Figure demonstrating the power law of practice (figure adapted from McLaughlin et al., 2010).

The power law of practice describes that average performance for a particular task is likely to improve logarithmically with the number of practice trials performed (Snoddy, 1926). This power function is based on the idea that average learning occurs at a rate where information at the start can be acquired quickly, then results may slow with what is left to be acquired. Heathcote and colleagues (2000) provide evidence that individuals, learn at more of an exponential law of practice. Exponential function curves begin with a gentle curve and become steeper, while logarithmic function curves are the inverse, starting steep and then levelling off. Nonetheless, practice on a motor task is not exactly exponential or even averaged to exactly a power function. The importance of these theories is to understand that practice occurs over the course of a curve (i.e., non-linear function) and can provide a useful constraint for theories of motor skill acquisition (Heathcote et al., 2000) (see Figure 1.2).

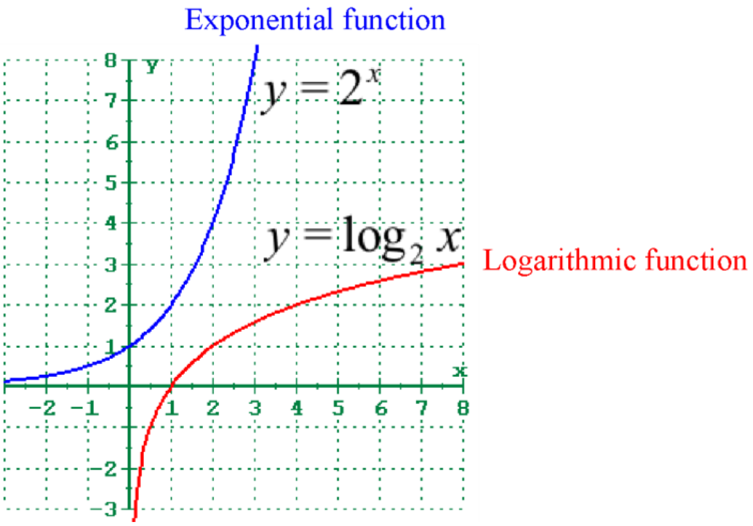


Figure 1.2: Difference between exponential and logarithmic function curves (figure adapted from Jones, 2023).

1.5 Distinctions Between Types of Feedback

Feedback is an important variable in motor learning. Feedback can be further separated into intrinsic and extrinsic feedback. The distinction between intrinsic and extrinsic feedback is important as it lends to the learner's experience and the takeaway from their performance. Intrinsic feedback is what the learner feels during their motor performance (e.g., a gymnast feeling off-balance). Intrinsic feedback comes from the learner's proprioception and somatosensory system. This feedback type can also be referred to as inherent, task-intrinsic, and response-produced feedback that is inherently available to the learner from sources (e.g., vision, proprioception).

Extrinsic feedback is provided by an external source such as a coach or watching their performance on a video and can be used in addition to intrinsic feedback. Extrinsic feedback can be further classified into knowledge of performance (KP) or knowledge of results (KR). KP refers to information about the individual’s movement characteristics that resulted in a specific outcome. KR relates to the information regarding the accuracy of the individual’s movement relative to the task goal (Schmidt & Young, 1991). An example of KP is a gymnast’s coach telling the gymnast to point their toes, and an example of KR is the gymnast seeing the judges' scores for their routine. When learning a motor skill, it is important to consider the feedback that an individual will be experiencing, and how to control feedback experiences. It is also important to use appropriate language when describing feedback experiences. Many retention tests in motor learning research will claim that there was a removal of feedback, when really there was a removal of extrinsic feedback only, as the learner can still experience intrinsic feedback through proprioception.

1.6 Requirements of Motor Learning

To make any inferences about motor learning, and to differentiate between it and motor performance, certain requirements must be met to conclude that motor learning has occurred. As motor learning is not directly observable, motor learning can only be inferred from recognizable changes in overt motor behaviours. A critical feature of motor learning is that changes to a learner’s capabilities relevant to the learned skill are relatively permanent such that the learning does not dissipate after practice ceases. Thus, experimental settings must be carefully constructed in order to have confidence that the observed changes are a result of motor learning and are not simply temporary performance gains. Given that motor learning is not directly observable, it is important to understand the most common methods of measuring motor learning processes. In a typical motor learning setting, learners will practice a motor task where performance may be measured as a function of trials. This results in the performance curve (e.g., Dubrowski, 2005). This practice of a motor skill is referred to as motor skill acquisition. Conditions and variables can be modified to assess their influence on motor skill acquisition and motor learning. As practice alone does not guarantee learning (Newell, 1991), retention and transfer tasks are used to demonstrate the permanence of motor skill acquisition, from which motor learning can then be inferred (Pinder et al., 2011; Shewokis, 1997). While a retention test has the potential to demonstrate the presence of motor learning, the depth of learning may be shallow if it can only be applied to a hyper-specific movement. Therefore, a transfer task can be used to assess the relative degree of generalizability of learning, or lack thereof, to novel (previously unpracticed) tasks or performance environments. Generally, the generalizability of motor learning can be thought of as an indication of the flexibility and/or adaptability of the previously acquired mechanisms that led to the learning permanence of the original skill. For example, repeated free throws in an empty gym from a stationary spot are likely to improve over repeated shots (motor skill acquisition). When performance in a subsequent session is demonstrated the next day (retention task), and if the performance levels demonstrated following acquisition are maintained, motor learning can be inferred to have occurred. However, the depth of this learning may be shallow if it is only applied to those specific practice conditions (i.e., empty gym, stationary shot, the location from the net). Therefore, a deeper understanding of true learning can be obtained with a transfer task, to determine the generalizability of motor learning (e.g., from various angles to the basket, in a crowded gym, or during a game).

1.7 Neural Correlates of Motor Learning

Humans have a complex multisensory process that is constantly receiving information from each sense (i.e., vision, audition, olfaction, gustation, and tactition). For this dissertation, the focus will primarily be on visual and proprioceptive sensory information. When a visual stimulus associated with a movement initiation cue is presented to the eye, activity in the occipital lobe is seen 100 ms after its presentation, with activity 260 ms later seen in the parietal, frontal, and motor regions as secondary processes influenced by earlier perception (Pins & Ffytche, 2003). From a movement and touch perspective, once humans receive sensory information from the surrounding environment, this information travels from the skin and proprioceptors to the spinal cord before reaching the brain (Thau et al., 2022). The neural processes responsible for motor learning are complex, as during each phase, and depending on the motor task, different cortical structures are involved. During the early phases of motor learning, for example, where high attentional demands are required, frontal, striatal, and parietal areas are activated (Marinelli et al., 2017; Poldrack & Gabrieli, 2001). The frontal lobe is responsible for executive functions, thinking, planning, problem-solving, emotions, and behavioural control, it also contains the motor cortex responsible for movement, and the sensory cortex responsible for sensations. The striatum is responsible for the preparation, initiation, and execution of movements (Báez-Mendoza & Schultz, 2013). The parietal area is involved in the understanding of the external environment to help process sensations. During the learning of a new motor task, more specifically, the prefrontal cortex and striatum (caudate nucleus and anterior putamen) are activated (Jueptner, 1998; Nakahara et al., 2001). The motor cortex is divided into the primary motor cortex, the premotor cortex, and the supplementary motor area. The primary motor cortex is the main contributor to the execution of movement (Bhattacharjee et al., 2021). The premotor cortex is responsible for the preparation of a movement, and motor control including spatial guidance. The supplementary motor area helps with planning sequences of movements and coordination of bimanual movements. A review by Jueptner and Weiller (1998) consolidates the results of studies demonstrating the brain areas activated during the various stages of motor learning by reducing the results from new motor tasks compared to well-trained motor tasks. The brain areas involved in the learning of new motor sequences were subtracted from the activation seen in well-trained motor tasks, to reveal activations in the striatum, globus pallidus, and cerebellum (Jueptner & Weiller, 1998). The role of the striatum in performing a new motor task is necessary for voluntary motor control (Mendoza & Schultz, 2013). The role of the globus pallidus in a new motor task is to control conscious and proprioceptive movements and helps to send information to the thalamus. The thalamus is an egg-shaped structure in the centre of the brain that relays motor and sensory information from the body to the brain (Sommer, 2003). Novice motor skill performance requires effortful cognitive control, and differences in neural activity are seen in well-learned motor skills.

During well-learned motor sequences, the sensorimotor cortex and posterior putamen are activated (Jueptner & Weiller, 1998). Once the motor learning phase switches to more automatism, there is optimizing activity of cortical and subcortical motor areas and a lesser reliance on the attention-executive networks (Cacciola et al., 2017; Nakahara et al., 2001). It is this attentive-to-automatic process, and the storage of learned procedures to be combined in the formation of new motor skills that permits such variety in behavioural repertoires (Hikosaka et al., 1995). Jueptner and Weiller (1998) describe that once a motor task becomes automatic, the prefrontal area of the motor system is no longer engaged, which allows for the motor system to take over and permits the prefrontal cortex to be engaged in another task. The prefrontal area of the motor cortex plays a role in cognitive control which includes attention, impulse inhibition, and cognitive flexibility There is flexibility depending on our task requirements where the prefrontal area (i.e., dorsolateral prefrontal cortex and striatum) are re-engaged when participants attend to their performance of an automatic task (Jueptner & Weiller, 1998) (See Figure 1.3, adapted from Dahms et al., 2020)

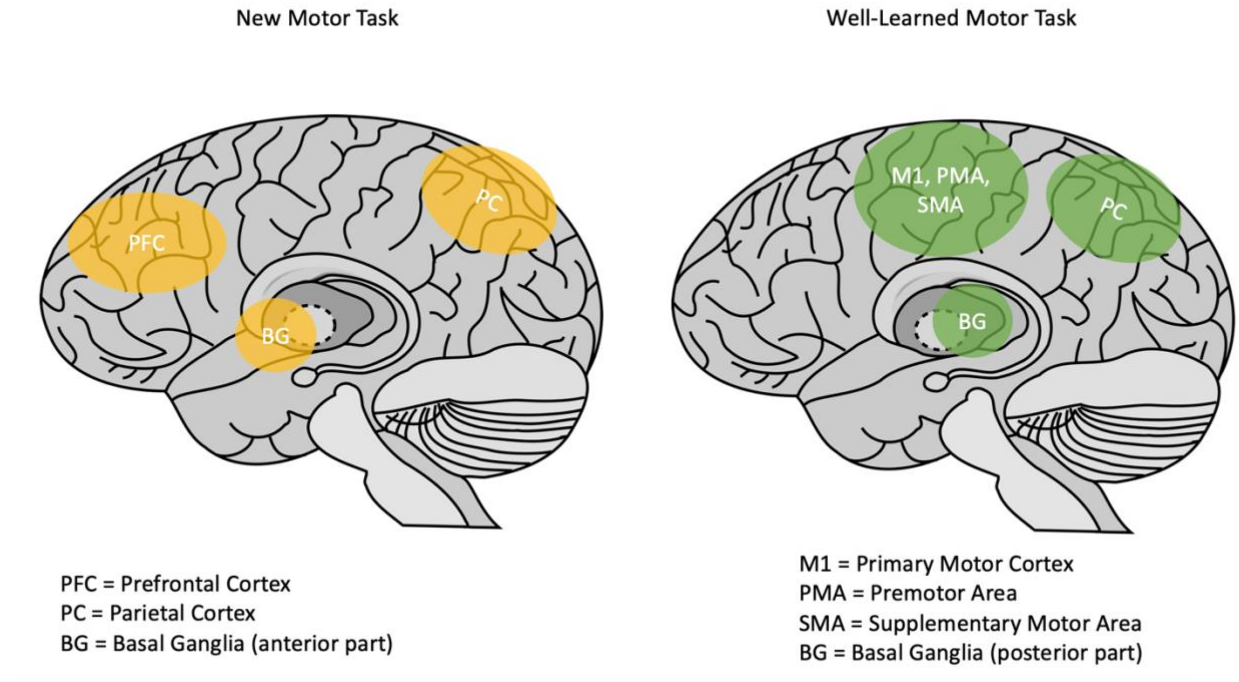


Figure 1.3: Illustrative representation of the locations of brain areas involved in performing a new motor task compared to performing a well-learned motor task (figure adapted from Dahms et al., 2020).

Thus, from a neurobiological perspective, motor learning can be considered in terms of neuroplasticity (i.e., the change in neural firing patterns and strength of neural connections in the motor cortex and striatum) that can be directly observed in overt changes to movement parameters with time (typically demonstrated by improved performance) (Hwang et al., 2022). Hwang and colleagues (2022) trained mice on a motor learning task and used cranial window surgery with in vivo imaging 1-2 hours after each motor training session to identify the neurons related to their behaviour changes. Immunostaining was used to identify which neurons were activated during the motor training, and which neurons were activated or reactivated in the training session 1 week later when mice still successfully performed the task. The motor task involved 30 reaches for 20 minutes using the preferred paw to grasp a food pellet through a plexiglass box with a vertical and bring the pellet to its mouth. This experiment found that motor learning recruits engram neurons in the motor cortex that are reactivated during motor performance. This motor learning increases dendritic spine density and strengthens the outputs to the striatum of primary motor cortex engram neurons (Hwang et al., 2022). These results indicate highly specific synaptic plasticity in the formation of long-lasting motor learning.

1.8 Theoretical Perspectives on Motor Learning

1.8.1 Information Processing Perspective

In studying motor learning, it is important to understand the various theoretical perspectives that are fundamental to the learning of motor tasks. There are two major theories for how learning occurs. The first major theory is based on the information processing perspective first described in a two-part paper from an engineering perspective entitled *A Mathematical Theory of Communication* (Shannon, 1948; Shannon & Weaver, 1949). Within these papers, a mathematical definition of information was used to conceptualize the abstract notion of how information is processed, which was later extrapolated to an application to humans. This theory proposes that information is processed in a two-part fashion wherein each piece of information received, serves to reduce remaining uncertainty. This theory suggests that the main goal of information is to decrease uncertainty. According to the information processing perspective, people receive information from the environment, process it, and then output a movement. For example, a baseball player is up to bat and watches the pitch come toward them. The information they are receiving is visual information about the ball which is transformed into motor information to swing the bat. Adapted from Shannon (1948) and Shannon and Weaver (1949), Fitts and Posner (1967) compares the information processing perspective to a computer; where there is an input of signals, processing of information, and output. To translate the computer analogy to human movements, the human receives information, processes the information, and creates a motor response (Fitts & Posner, 1967). Similar to computers, humans can solve problems by linking new information with previously stored information. For example, humans receive sensory information about a motor task which is converted into neural activity, where sensory memory is created. Sensory memory filters out irrelevant information and only sends necessary information to the next stage. When this information is attended to, this sensory memory moves into short-term memory. How much information can be processed into short-term memory depends on several factors and can vary from person to person (e.g., cognitive load, amount of information being processed, one’s focus, one’s attention, one’s perception of the task's importance, etc.). With the practice of the motor task, an internal representation of the sensorimotor information can be encoded and retrieved as needed into long-term memory. The information processing model by Schmidt and colleagues (2018) divides the whole process into distinctive stages. The model begins with the onset of a stimulus, where the individual identifies the stimulus (e.g., incoming baseball), selects a response (e.g., to swing the bat), the response is programmed (e.g., when there is an incoming baseball, initiate bat swing), and there is a response output (e.g., swing the bat to hit the baseball) (Schmidt et al., 2018). This model considers the three stages of stimulus identification, response selection, and response programming to be the information processing model. The information processing perspective is a main theory into how human motor learning and control are a result of a complex interplay between information received from the environment around us and use cognitive processes to execute a movement. While the representation of how humans process information is similar to that of a modern computer, this metaphor has its limitations. Computers are not faced with emotions, and motivations like humans are, which has a large impact on human motor performance. It may also be naive to consider that each piece of additional information brought to the system will always result in a reduction of remaining uncertainty. It is possible for additional sensory information to create an increase in uncertainty and lead to movement performance decrements.

1.8.1.1 Transfer Appropriate Processing

One important aspect of an information processing theoretical framework is that it allows for reasonable inferences to be drawn with respect to if, how and the degree to which the learning that results in the acquisition of a motor skill can be transferred to a new skill or a novel condition. Stated differently, the underlying processes of learning that develop during the acquisition of a skill, as intrinsic and extrinsic information is processed, may be more or less generalizable (see section 1.10 of this thesis) to new situations (or, conversely, may remain specific to the original skill). Specifically, the more generalizable the learning is, the more appropriate the information processing is to transfer conditions or situations.

This concept of transfer-appropriate processing (e.g., Lee, 1988; Schmidt & Bjork, 1992) was initially applied to memory studies where researchers examined the amount of overlap between processes engaged from a first study exposure to the processes engaged in a second test exposure (Bransford et al., 1979; Morris et al., 1977). The theory has since been applied to motor learning and is a common perspective in this field of research. In the context of motor learning, transfer-appropriate processing holds that motor learning can be optimized when the processing activities in a transfer test are similar to the processing activities undertaken during acquisition. Previous experience with a similar task will typically be beneficial in this situation. Edwards and Lee (1984) examined blocked versus random practice conditions (see section 1.9.3 in this thesis) with children and special populations and found positive transfer with their random practice interventions. These random practice conditions are a classic example of contextual interference (see section 1.9.3 in this thesis) and can better represent the unplanned or random elements in activities of daily living in these rehabilitation motor learning studies. Similar appropriate transferring is seen with Rajan and colleagues (2019), using a transfer of motor learning from one body part, to another in what is operationally defined and termed ‘anthropometrical’ transfer later in this thesis (see section 2.5.3). Their study examined the whole arm and transferred the motor task to just the hand on a robotic exoskeleton device to control an on-screen cursor task. This makes sense that there would be transfer-appropriate processes, as motor skills could generalize from proximal to distal effectors and distal to proximal effectors (Rajan et al., 2019).

With a transfer test, researchers can determine if the learning was task-specific, or if the learning can be applied more broadly to tasks that are different from those originally acquired. For the purposes of this thesis, ‘generalizability’ differs from ‘transfer’ where transfer refers to attempting a new motor skill that can either result in motor skill generalizability or motor skill specificity (see section 1.10 of this thesis). The term transfer is typically associated with a transfer task or a transfer test without directionality of the results (i.e., generalizability or specificity). There are essentially only three possible outcomes of a motor skill transfer test (i.e., positive transfer, negative transfer, and neutral transfer). To determine if there was a positive transfer (or generalizability of the learned motor task) the experiment would result in transfer performance that is better than it would have been had the original task not been acquired. In these situations of positive transfer, it has been suggested that the process of learning the original skill likely provided the learner with a “head-start” on the novel task. Second, if an experiment is showing motor learning specificity the results, while demonstrating performance improvements in retention testing, would reveal no performance benefits on the transfer task. Such a result would suggest that there was no beneficial effect of practicing the previous skill on the novel skill. In this situation, the processing activities involved in practicing the original task are specific to that task. The third potential outcome of a motor task transfer protocol is considerably more rare than the first two: Negative transfer wherein the practicing of the original task has a detrimental effect on the learning of the novel task. Research revealing true negative transfer effects (non-transient, disadvantageous influences of prior practice) is scarce and our understanding of its causes is incomplete however theoretical accounts of negative transfer typically involve the idea that previously developed knowledge structures acquired during the original practice are maladaptive to change and will result in poor learning outcomes in tasks with changed motor demands (e.g., Woltz et al., 2000). Such accounts suggest that the learner must, in effect, “unlearn” the initial motor task and relearn the novel test under its new context.

1.8.1.2 Models from an Information Processing Perspective

Several models have been developed from an information processing perspective that describe how motor learning occurs (e.g., Fitts and Posner’s three-stage model [1967], Adams’ closed-loop model [1971], Gentile’s two-stage model [1972], and Schmidt’s Schema theory [1975]). For the purposes of this thesis, the models outlined below will begin with Fitts and Posner’s three-stage model (1967).

Fitts and Posner's three-stage model of motor learning includes the previously mentioned cognitive, associative, and autonomous stages (Fitts & Posner, 1967). The cognitive phase entails the individual receiving information about how to perform a movement and continuously integrating extrinsic (i.e., from an external source) and intrinsic (i.e., from an internal source) feedback they are receiving. Cognitive phase movements may be slower, inconsistent, and inefficient, all requiring significant cognitive activity (Fitts & Posner, 1967). Fitts and Posner (1967) suggest that this first cognitive stage requires attention to the specific body parts required to make the desirable movement, making these movements under conscious control. During this first phase, the individual typically is experiencing high variability of motor performance, and the duration of this phase will depend on task complexity (Anderson et al., 2021). The second phase, the associative phase, involves movements becoming more fluid and reliable, requiring less cognitive activity than the first phase (Fitts & Posner, 1967). During this phase, some movements will still be under conscious control, whereas others will be more automatic (Fitts & Posner, 1967). The final stage is the autonomous stage, where movements are more accurate and consistent with less cognitive activity being required (Fitts & Posner, 1967). When motor learning enters the autonomous stage, attention can be focused on other aspects of the motor task such as tactical choices, the strategy of movement, greater range of motion, or increased speed and acceleration (Fitts & Posner, 1967). In the context of this thesis, it should be noted that 'automaticity' does not necessarily equate to expertise. It may serve as a foundation for specificity or impede the broader application of motor skills.

Adams' (1971) closed-loop theory proposes that motor learning occurs through the refinement of perceptual-motor feedback loops. The motor system relies on sensory feedback to continually execute skilled movements. This theory consists of two parts: a memory trace and a perceptual trace. The memory trace is responsible for selecting and initiating the movement, while the perceptual trace develops during practice and serves as the reference for correctness. A practical example of the closed-loop theory is drawing a 5-centimetre (cm) line with a pen. This model would suggest that though you can draw a 5 cm line, you will need a new memory and perceptual trace to draw a 7 cm line. This is because this model has such a heavy reliance on sensory feedback to develop and strengthen memory and perceptual traces. This model mainly applies to discrete, closed motor tasks. This closed-loop model allows performers to use sensory feedback to improve their movements. However, this model has limitations in being able to extend to practical applications to continuous and open motor skills. This model suggests that a motor program is created for every single motor movement and that they each must be created, stored, and recalled when needed.

As a response to Fitts and Posner's (1967) model, Gentile (1972) developed a model to address the previous model's limitations. Gentile (1972) created a model seeking to refine Fitts and Posner's (1967) original Stages of Learning work by taking this open vs. closed skill distinction into account. Comparable to the Fitts and Posner (1967) cognitive stage, Gentile (1972, p. 5) refers to the initial phase of learning as "getting the idea of the movement". This stems from an interaction with the external environment to solve a problem that has emerged, creating a movement goal. The individual must learn how to release the specific movement pattern required to achieve that movement goal. Generally, the number of environmental events related to that same goal will increase, with spatial characteristics also changing over time, allowing the degree of spatial/temporal movement control that an individual must also increase over time. To untangle the range of motor patterns best suited to yield the appropriate movement goal, the individual must identify an effective motor plan, which becomes more difficult in complex stimulus environments (Gentile, 1972). Gentile uses terms by Poulton (1957) of "open" and "closed" environments to explain the options that the individual has before outputting their movement. According to Gentile (1972), movements are on a continuum of "open" to "closed" environments but there is value in dichotomizing the nature of the environmental context as either closed or open.

Gentile (1972) describes the initial stage of acquisition to be similar for both environments, where the learner tries to find a general motor organization that works to produce the desired outcome. The main task for the individual at this early stage is to attend to information about the environmental conditions (i.e., open or closed) that are controlling their movements. Gentile (1972) adopts concepts from the “Test-Operate-Test-Exit” (“TOTE”) theory, developed by Miller and colleagues (1960), which describes the motor plan (i.e., a preconceived image or general plan of action) used to direct the motor output. “TOTE” matches intentions with movement outcomes, where “Test” is the initial image or plan of the intended movement, “Operate” involves the musculature contractions involved with producing the movement, the second “Test” is comparing the movement feedback against the initial image of the desired movement, and “Exit” is interpreting the match or mismatch of the feedback, ending in a termination of the operations, or a modification of the operation. “TOTE” is then used as a hierarchical system where the ”Operate” phase of a movement plan can serve as a test for subroutines, allowing for additional movement organizations to be created. Gentile (1972) adapts this concept to suggest that first there is an image or movement plan before output, second, that movement output information is fed back to the individual and to be matched against the initial plan, and third, having an evaluation of the feedback to determine at which point to terminate or amend the action. After movement outcome information (i.e., intrinsic and/or extrinsic) is fed back to the individual, there is a decision-making process that occurs for the learner to formulate their next response. Gentile (1972) outlines four possible outcomes during the evaluation phase of the decision process surrounding “Was the movement executed as planned? Yes/No" and "Was the goal accomplished? Yes/No". If "Yes" the movement was executed as planned, and "Yes" the goal was accomplished, then the individual got the idea of the movement. If "No" the movement was not executed as planned, but "Yes" the goal was accomplished, then a "surprise" experience occurs where the learned experiences the goal even though their movement did not go as planned. If "Yes" the movement was executed as planned, but "No" the goal was not accomplished, then the "something's wrong" outcome results in the individual needing to re-evaluate whether the environment or movement matches the initial evaluations of the identification process. In the last scenario, "No" the movement was not executed as planned, and "No" the goal was not accomplished, then, "everything's wrong" and can lead to several alternate strategies or quitting.

Stage two of Gentile's (1972) model is "Fixation/Diversification" which occurs after the individual has acquired a general idea of the motor pattern that seems to work well, then the individual will progress into this second stage to increase the consistency or to refine some of the movement characteristics. During stage two, the individual is now progressing into attaining a particular level of skill with their motor task. The experience in stage two will vary per instance depending on whether the motor skill is occurring in an open or closed environment. In a closed environment, the environmental conditions are fixed, allowing the individual to predict in advance what the context of their next environmental conditions will be. During stage two in an open environment motor task (i.e., diversification), the experience can be quite different from that of a closed environmental condition. An individual in an open environment context must learn an array of motor patterns. Each motor output from one attempt to the next may involve a slight modification to the movement. In these open environments, no single movement pattern will be the solution to all possible outcomes. Thus, the individual must have a repertoire of possible movement outcomes to be able to move in accordance with other moving objects or other individuals, making the demands of motor learning in open environments more complex.

As an argument against Adam's (1971) closed-loop model, and taking into account the information processing requirements outlined by both Fitts and Posner (1967) and Gentile (1972), Schmidt, (1975) developed a schema based theory that essentially proposes that humans do not learn specific movements (based on a multitude of individual motor programs). Rather, Schmidt's (1975) schema theory argues that learned movement patterns involve the development of far few motor programs that can be "generalized" across many different movement parameters. A generalized motor program, as conceptualized by Schmidt (1975) is a smaller pre-set set of motor commands that can be retrieved from memory and customized for a specific situation before initiating movement. This theory is open-loop in nature wherein augmented feedback (i.e., information regarding movement execution and outcome from an external source resulting respectively in knowledge of result or knowledge of performance) may or may not be available but it does not, in and of itself, control the action. This theory works best for fast, ballistic, and more automatic movements (e.g., a golf swing) where there is little time to change the movement mid-swing. Schmidt's motivation in developing this schema-driven explanation of motor learning was to account for two fundamental problems with Adams' (1971) closed-loop theory: Novelty of movement (i.e., how can new movements be executed if there has been no prior opportunity to develop the perceptual and memory traces needed to perform them?) and storage (i.e., the inherent inefficiency in the requirement to develop and retain for future use a seemingly infinite number of individual motor programs). Although it has been suggested that humans are capable of storing about 100,000 programs for speech, this number would increase to countless outcomes for the storage of human motor movement possibilities (MacNeilage, 1970). Schmidt's (1975) model suggests that humans must have a more efficient way to store motor programs. The next concern with Adam's (1971) closed-loop model is the novelty problem and the lack of explanation for how an individual can produce a novel movement or many variations of a particular motor skill. For example, Adams (1971) would not be able to explain how to throw a bean bag 7 meters and then 7.5 meters. Based on Adam's (1971) closed-loop model, a perceptual trace is created for each movement, for example, the 7-meter bean bag throw. With practice, the perceptual trace for the 7-meter throw gets thicker and thicker. When called on, the memory trace for the 7-meter throw can be used, but there are no traces for 7.5-meter throws, the individual would not be able to accurately throw shorter or farther.

Thus, closed-loop learning models such as Adams' cannot adequately explain how the thrower can have a repertoire of different throw distances that are slightly different, yet characteristic of all the previous ones. In Schmidt's (1975) model, however, learners can produce different movements within a class of movements by adjusting certain parameters that will change various movement outcomes. This explanation is a solution to the previous model's limitations where the individual would specify the appropriate parameters for the movement. When patterns of similar movements are examined, there may be elements of the movement that are easy to change, while other aspects are fixed from movement to movement, termed invariant (Schmidt, 1985). These parameters are features of a movement (e.g., the amount of force from the muscles to contribute to the movement). By scaling a parameter of a movement, people can produce variations of the movement within the class of movements. For example, as a performer practices a movement such as throwing the bean bag at various distances, they will learn the ***relationship*** between the amount of force required and the outcome of the throw, not the individual distances themselves. By practicing throwing the bean bag at these different distances, the performer will improve their understanding of the relationship between their control of the parameters and the throw outcome. In Schmidt's (1975) theory, this relationship between parameters and the movement outcome is collected in two schemata: recall schema and recognition schema. The recall schema relates the movement outcome to parameters such as the amount of force in an overhand baseball throw. The recognition schema connects the expected sensory results of a movement to the actual outcome of that movement.

1.8.2 Dynamical Systems Perspective

Not all models of motor learning involve a top-down processing of information, however. One influential model of learning that downplays such resource-heavy cognitive processing requirements suggests that movement in general, and motor learning in particular, rely less on cognitive processing and more on the dynamic physical constraints of the mover/learner. This dynamical systems perspective is also a multifaceted and complex perspective to explain motor learning but it is more focused on an ever-changing interaction between the individual, the task, and the environment. Bernstein (1967) describes dynamical systems with a focus on the progression in solving the problem of degrees of freedom. In terms of human movements, degrees of freedom relate to the number of independent variables (e.g., joints, muscles) that need to be controlled while executing a movement (Bernstein, 1967). For example, an elbow joint has two degrees of freedom as it can afford only a flexion and an extension movement. To learn new movements, individuals must learn to coordinate their actions with the number of associated degrees of freedom. Bernstein (1967) breaks down this model into three stages. Stage one consists of 'freezing degrees of freedom' where individuals utilize control or limit the number of joints and muscles that move independently. The second stage involves 'releasing degrees of freedom' where individuals no longer need to isolate the body segments after they can successfully perform the basic movements of the motor skill (Bernstein, 1967). The third stage of the Bernstein (1967) model is 'exploiting degrees of freedom' where individuals can begin to exploit reactive forces and passive dynamics of the body and environment, allowing for more efficient and effective movements.

The dynamical systems perspective on motor learning suggests that motor skills will emerge naturally as practice occurs or experience with a movement develops. This theory states that any movement outcome depends on the individual's body (system) as well as their interaction with the environmental conditions (dynamics). Through the dynamical systems perspective, motor development is seen as probabilistic, with different factors in the environment and individual that can affect these probabilities. The body is composed of a complex system with many interacting parts, which lends to the probabilistic approach to movement outcomes.

The main takeaway regarding the dynamic systems perspective is that humans are complex systems that have an inherent capacity to self-organize. Given various tasks, environments, and individual situations, many great movement solutions may arise, and these factors can be quite pivotal in an individual's dynamic motor behaviour. For example, the dynamical systems perspective would be a snowboarder learning to use gravity to their advantage down the slopes. According to this perspective, the snowboarder self-organizes to emerge the necessary next movements.

1.8.2.1 Ecological and Systems Models of Motor Learning

Motor learning can also be explained through ecological theory and systems models. The ecological theory finds its origin in the earlier work of Bernstein (1967) on the control and coordination of movement and in Gibson's (1979) theory of direct perception. The ecological theory suggests that humans perceive their environments directly and without mediation by cognitive processes. This approach focuses on how a person's surroundings shape their perception and behaviour based on the opportunities and limitations they afford. The individual, the task, and the environment will interact to provide perceptual information used to control movement. The stimulus to accomplish a desired movement task goal is what facilitates motor learning according to this approach.

A systems model described by Shumway-Cook and colleagues (2007) builds on these concepts by positing a framework of multiple body systems overlapping to activate synergies for movements to occur that are driven by functional movement goals. Similar to the ecological theory, the systems model also considers the interaction of the individual with the environment, but with a more goal-directed behaviour that is task oriented. The movement results from an interaction of multiple systems working in synchrony to solve a motor problem while accounting for the adaptability of motor behaviour depending on the environmental contexts. The theories mentioned previously, including information processing, dynamical systems, ecological, and systems models, each offer insights into motor learning and, to varying degrees, attempt to account for the phenomenon of transfer. In this thesis, the focus will primarily lean towards employing concepts from the information processing perspective, especially in relation to transfer-appropriate processing. Both the information processing perspective and the concept of transfer-appropriate processing underscore the significance of the ways in which we encode, store, and recall information. The information processing theory lays the groundwork for understanding how sensory inputs and memory processes interact, whereas transfer-appropriate processing theory emphasizes the crucial influence of context and the congruence between the encoding of information and its later retrieval in the context of motor learning. With these theoretical perspectives in mind relating to the broad outcomes of human motor learning, we can better strategize how to structure the practice of a motor task.

1.9 Conditions of Practice

1.9.1 Deliberate Practice

An individual can inadvertently practice without self-investment in the motor task, which is why it is important to highlight deliberate practice where activities have been explicitly designed to improve the current level of motor performance (Ericsson et al., 1993). Deliberate practice is when an individual is putting effort into the task with the goal of personal improvement in motor performance. Ericsson and Harwell (2019) outline how deliberate practice differs from other forms of practice (i.e., purposeful practice, structured practice, and naïve practice).

Alternatively, when individuals are practicing in the absence of, or with limited exposure to individualized evaluation and guidance by a teacher or coach, this is referred to as ‘purposeful practice’ (Ericsson & Harwell, 2019). When practice is in a group or team setting guided by a coach or teacher, also without individualized feedback, this is referred to as ‘structured practice’ (Ericsson & Harwell, 2019). ‘Naïve practice’ are activities that are motivated by other factors than the goal of improvement such as playing games with friends or executing a job in response to a demand from an external factor (Ericsson et al., 1993; Ericsson & Harwell, 2019).

When it comes to these various types of practice, there are positives and negatives associated with each of these types of practice. Depending on the desired outcome of the individual, each type of practice has space in the practice space. If an individual is serious about their movement goals to improve, then the individualized feedback style of deliberate practice may be best. If a coach or teacher's resources are limited, perhaps group settings or limited meetings with coaches and teachers are the best approaches in purposeful or structured practice. If an individual is practicing a task for the experience, or only wants to try it once and isn't concerned with ideal motor performance, then naïve practice best fits this situation. In terms of motor learning research, deliberate practice is ideal as it contains tailored feedback for the individual to improve toward the movement goal.

1.9.2 Massed vs. Distributed Practice

Distributed practice is a learning strategy that involves breaking up the practice into multiple sessions spaced out over time (e.g., 20 trials per day over 3 days), compared to a massed practice involving longer practice sessions (e.g., 60 trials performed on a single day). While massed practice can be seen as an efficient use of time to perform all the practice at once, this type of practice can be fatiguing. When practice is dispersed over time in distributed practice, this can allow for recovery, and give the individual time for mental rehearsal and feedback, with a disadvantage being that it can be time-consuming. It is important to consider in motor learning research when using massed and distributed practice, or comparing studies that use different forms of practice, to ensure the same number of trials are occurring between groups. Massed practice is continuously repeating a movement without taking breaks which can be beneficial for short time frames, and immediate performance improvements. Massed practice does have limitations with its short time frame, as it may not have time for augmented feedback, and the repetitions may be fatiguing for the learner. Distributed practice will allow time for recovery and time for augmented feedback. One of the drawbacks of distributed practice is its time-consuming nature.

1.9.3 Blocked vs. Random Practice

How practice is structured can also be categorized into blocked and random practice. Blocked practice refers to practicing the same skill under the same conditions, repeatedly, before moving on to the next skill. Random practice refers to practicing the motor skill with variability between each attempt. Blocked practice will have a low contextual interference which is described in a review by Magill and Hall (1990) as a learning phenomenon where interference during practice is beneficial to skill learning. Practice performance tends to be worse with higher levels of contextual interference, but retention and transfer performance are generally better. Lower levels of contextual interference, instead, can result in better practice performance but lower retention and transfer performance (Magill & Hall, 1990). This contextual interference originated from verbal learning research with evidence of ‘intratask interference’ (Battig, 1972). Prior to this research, the prevailing idea was that interference would lead to a decrease in performance. This research was able to demonstrate that under certain circumstances, interference could be beneficial to performance. The intratask interference principle was expanded to represent more general ‘contextual interference’ including intrinsic and extrinsic factors to the task being learned (Battig, 1972). Shea and Morgan (1979) found that this contextual interference effect could be applied to motor skill learning contexts as well. Shea and Morgan (1979) define blocked practice as practicing the same skill under the same conditions and leads to more rapid gains in motor performance, due to its low contextual interference, but limited generalizability when variability is introduced. Random practice is the adding of variable task requirements into practice which slows performance but can improve retention and generalizability to other contexts of the motor skill, due to its high contextual interference (Shea & Morgan, 1979). In the Shea and Morgan (1979) experiments, the participant was tasked with responding to a light stimulus as quickly as possible by knocking down a series of hinged barriers in an order specific to the colour of the signal to respond. With the random condition, three different possible signals would be illuminated, making the task primarily a choice-reaction paradigm. Under the blocked condition, only one signal would illuminate, making the participant’s response a simple-reaction paradigm. Lee and Magill (1983) replicated the procedures of Shea and Morgan (1979) and altered the procedures such that the contextual variety and reaction paradigm could be controlled. In experiment one, Lee and Magill (1983) created factors of cued vs. uncued to denote whether a warning light was provided and blocked vs. random referring to the contextual variety in the forms of the following groups: cued-blocked, uncued-random, uncued-blocked, cued-random. The retention test involved all groups performing the motor task in random order. The findings of Lee and Magill's (1983) experiment one support Shea and Morgan's (1979) contention that random contextual variety conditions facilitate the retention of motor skills relative to blocked practice, and this effect is not due to an interaction of the practice schedule with a reaction paradigm. Lee and Magill added an explanation for the process of using active regeneration for a new movement plan in a chapter (Lee and Magill, 1985) that synthesized some of the conceptual findings of their work. The chapter described how forgetting the specifics of a previously generated action plan will force the learner to reconstruct an action plan on a subsequent repetition of the movement goal (Lee & Magill, 1985). By having the practice of a particular movement goal spaced, the individual learns more about the process of developing and implementing an action plan (Lee & Magill, 1985). This effort-related learning can be explained by using a math example. For example, if a child is trying to remember math problems, they can practice 5 x 4 = 20, and go through the effort of counting by fives on their fingers. When they practice 5 x 4 again and again, they will eventually skip over the effort of counting on their fingers, and have the answer 20 memorized to reiterate. By adding in different math problems such as 5 x 5, now the child can be effortful again in counting by fives. Moving on to 5 x 5 forces the child to forget about 20. When 5 x 4 is revisited, rather than reacting with memorization, the act of forgetting forces this active regeneration of effortful counting. This process of forgetting and reconstructing the solution by Lee and Magill (1985) is what leads to improved learning and is in line with the contextual variety effect (Battig, 1972).

The elaborative-distinctiveness hypothesis (Shea & Morgan, 1979; Shea & Titzer, 1993; Shea & Zimny, 1983) and the forgetting-reconstruction hypothesis (Lee & Magill, 1983; Lee & Weeks, 1987) are both explanations for the contextual interference effect. They differ where the elaborative-distinctiveness hypothesis uses intertask comparisons and embellishment of task-relevant information to create more elaborate information processing. More elaborate information processing is thought to result in a more comprehensive memory trace (Lin et al., 2008). Alternatively, the forgetting-reconstruction hypothesis suggests that a previously constructed action plan is more likely to be available in working memory when the same task is practiced repeatedly. When practice is random, however, this forces the learner to abandon the action plan previously constructed because they have a different task (Lin et al, 2008). Compared to a blocked practice schedule, a random practice schedule engages the learner in deeper cognitive processes which can lead to a stronger motor memory representation for retention (Kantak & Winstein, 2012). Allowing for more inter-task comparisons in a random practice schedule leads the learner to a stronger and more elaborate memory representation (Wright, 1991).

In summary, the use of scheduling random task requirements in practice during acquisition is thought to induce a contextual interference effect. When the learner is given blocked practice scheduling in the acquisition, there may be evidence of more immediate performance gains, but the learner may have limited motor skill generalizability when variability to the motor task is introduced in the future (i.e., a lower degree of learning). Conversely, when the learner experiences random practice, or trial-to-trial practice variability during acquisition, immediate motor performance may be lower but the future retention and generalizability performance is increased. With the distinction between motor performance and motor learning, the contextual interference effect is a great example of how one snapshot of a learner’s performance in acquisition can be deemed localized and specific to that time and place (Kantak & Winstein, 2012). To go beyond immediate motor performance and determine whether motor learning has occurred, the contextual interference effect stresses the importance of using a retention and transfer test to assess the relative permanence of motor learning.

1.9.4 Part vs. Whole Practice

Whole practice is when the motor skill is practiced in its entirety, compared to part practice is when the motor skill is broken into smaller parts to be practiced in isolation before joining the segments together (McGuigan & MacCaslin, 1955). Part practice can help link sequential movements into a single movement pattern over time. With practice, the parts can be “chunked” together into a single, cohesive movement. The decision of whether to break a motor task into parts versus keeping the motor task whole can depend on the needs and skill level of the learner. When the motor task is low in complexity, and the learner has high interdependence, whole practice may be more suitable. When a motor task has high complexity, and the learner has low interdependence, part practice may be more appropriate. Skill complexity has been defined in a taxonomy of human perceptual-motor abilities by Fleishman (1972) to be used as a classification system to underlie any complex motor task. Within the review by Fleishman (1972), there is the understanding that the skills involved in complex activities can be described in terms of more basic abilities (Fleishman, 1972). “Motor skill complexity is defined as the number of parts or components of a skill; meaning the more parts or components a sill has, the higher it is in complexity” (Kiefer et al., 2014, p. 2).

1.10 The Generalizability and/or Specificity of Motor Learning

Whether a motor skill has transfer-appropriate or specific properties is a key theme of this thesis. It is known that sometimes motor skills are generalizable to other motor tasks, and in rarer instances, learned motor skills are specific to one motor skill and can be detrimental to performance on other motor skills. Where this line between generalizability and specificity is drawn is unclear. "Unfortunately for psychologists, the human organism was not designed for the convenience of researchers" (Miller, 1956, p. 136). This thesis aims to further explore how many accounts of true motor learning specificity are there and to examine whether there are commonalities between these types of movements using a scoping review. The scoping review will pose key areas of inquiry for future researchers looking to implement motor learning experiments with true transfer tests (Chapter 2). Further, the experimental work in this thesis aims to create an experimental protocol to promote a true transfer test (Chapter 4). With a true transfer test implemented, any robust findings of motor skill generalizability or specificity will have the opportunity to present themselves cleanly and clearly. With these theoretical perspectives in mind as to why specificity of practice exists (i.e., sensorimotor representations, movement patterns, and incompatible knowledge structures), these concepts represent the foundation of this thesis.

1.10.1 Generalizability of Motor Learning

Everyday activities of daily living suggest that we can learn and have a repertoire of multiple motor skills. How a repertoire of motor skills aids the learning of new motor skills is referred to as motor skill generalizability. In previous motor learning literature, 'generalizability' has been used to describe our ability to apply what has been learned in one context to another context (Krakauer & Shadmehr, 2006). This refers to the extent to which practice on one task contributes to the performance of other similar skills, sometimes in other contexts. Seeing motor task generalizability in a transfer task is typically seen as an extension and confirmation of having learned the initial motor task. Currently, retention and transfer tests are motor learning researchers' gold standard to best assess the success of motor learning (Pinder et al., 2011; Shewokis, 1997).

In traditional motor learning experiences, the series of events typically include acquisition (i.e., where the learner is practicing the motor skill), retention (i.e., where the learner is assessed on the relative permanence of the learned motor skill), and transfer (i.e., where the learner is assessed on an additional degree of learning to demonstrate whether the skill acquired from the acquisition is generalizable to a similar motor task). Transferring to a new motor task has been widely used in motor learning to permit making motor learning claims. The idea is that if the motor skill has been retained based on the retention task, then learning has occurred. To solidify this claim, if learning has been generalized to a similar task in a transfer task, that this also advocates motor learning has occurred. Work by Sigmundsson and colleagues (2017) describes the learning process to occur in four phases: starting with understanding the skill, acquiring, and refining the skill, automatization of the skill, and ending with a generalization of the skill. The final stage in this model is suggested to only be achieved if the skill has been well learned and maintained (Sigmundsson et al., 2017). It is also suggested that some individuals may have difficulty reaching the generalizability stage if they have not automated the skill due to a lack of practice (Sigmundsson et al., 2017).

1.10.1.1 Theoretical Perspectives in Generalizability of Motor Learning

Theoretical perspectives informing contemporary thinking, in support of motor skill generalizability are the principle of identical elements, general motor ability, general motor programs, and transfer-appropriate processing. Generalizability can be construed using the principle of identical elements, where the transfer is predicted based on element similarity (Thorndike, 1906). In Thorndike's (1906) explanation, the theory of generalizability is discussed as a spread of practice that occurs only where identical elements are present. For example, learning to ride a moped could be learned relatively easily after having already learned to ride a bicycle based on both equipment-sharing steering and balance similarities.

The concept of general motor ability is broad and covers all motor performance being based on a single, all-encompassing capability (Adams, 1987). This concept is structured around humans being equipped with the capability to move, and this capability brings relevance to other motor tasks in the future.

General motor programs are the theory that a particular class of actions is stored in memory and that its unique corresponding motor pattern will occur whenever the program is called upon. As mentioned earlier in this chapter, the theory with general motor programs is that individuals will have several pre-structured commands that the motor system can call on. Schmidt (1975) suggests that rather than each movement having its separate motor program associated with it, individuals have more universal programs for a given class of motor actions. For example, rather than having a single throwing a baseball motor program, individuals will have an overarm throwing pattern (Schmidt, 1975).

The transfer-appropriate processing theory is one attempt to explain why the generalizability of motor tasks may exist. Some of the earlier work on this theory was developed by Broadbent (1958) with multistore models in dichotic listening. To comprehend how information is transferred, it is important to understand the process of selecting and filtering relevant information. Broadbent (1958) proposed that information is first held transiently before entering the limited-capacity processing channel. These items can be held for a short term by recycling them. From there, the information can be transferred into and retained in more permanent long-term storage. This model was modified into memory is classified into three levels of storage with sensory stores, short-term memory and long-term memory (Murdock, 1967). Craik and Lockhart (1972) examined the multistore models, questioned their adequacy, and proposed an alternate framework for levels of processing.

A distinction was made by Craik and Lockhart (1972) between short-term and long-term memory referring to experimental situations, and the terms short-term and long-term store referring to the two relevant storage systems. A short-term store has a limited capacity, whereas a long-term store has no known limit in verbal memory research (Broadbent, 1958). Verbal items can be kept in short-term storage that is coded phonetically, whereas long-term storage is more used for semantics. Craik and Lockhart (1972) present a critique of the previous multistore framework where they believe the approach does not provide satisfactory grounds for distinguishing between separate stores. The inadequacies lay in the concepts of capacity, coding, and retention. In terms of capacity, studies have attempted to measure the capacity of short-term memory, but results have varied depending on whether the task was related to words, letters, or digits (Crannell & Parrish, 1957). Craik and Lockhart (1972) argue that the concept of capacity is a limitation of the previous multistore processing model. In terms of coding, researchers originally found that information in short-term stores was coded acoustically and that coding was predominantly semantic in long-term stores (Conrad, 1964). Since then, research is unclear on the distinction between short and long-term stores with short-term stores accepting a variety of codes (e.g., verbal, visual) (Kroll et al., 1970). This brings uncertainty as to whether or not short-term stores can also hold semantic information. Craik and Lockhart (1972) argue that the coding concept is likely formulated based on the demands of the material to be remembered. In some cases, acoustic coding may be adequate or all that is possible. In other cases, processing to a semantic level may be both possible and advantageous. These memory stores are defined based on their forgetting characteristics. Given that humans recognize pictures, faces, tunes, and voices after long periods of time, it is clear that humans have long-term memory for non-verbal information. Such variety makes it difficult to distinguish between sensory memory and pictorial memory (Craik & Lockhart, 1972). The extent to which humans can retain that information can be based on familiarity, compatibility, and meaningfulness of the stimuli (Craik & Lockhart, 1972).

The levels of processing have since been broken down into early perception involving the rapid analysis of stimuli (e.g., sensory features such as lines, angles, brightness, pitch, and volume). Then later perception stages are concerned with matching the input against stores from past learning. These processing stages are referred to as 'depth of processing' where the greater the depth of the stage, the greater degree of cognitive analysis (Craik & Lockhart, 1972). After the stimuli have been recognized, they may undergo additional elaboration processing where it may trigger associations, images, or stories based on past experiences, called 'elaboration coding' (Craik & Lockhart, 1972). From this perceptual analysis, a memory trace is created. Specifically, trace persistence is a function of depth of analysis, with deeper levels of analysis being associated with more elaborate, longer-lasting, and stronger traces (Craik & Lockhart, 1972). Retention is a function of depth where various factors such as stimuli that is more familiar, and meaningful will be processed deeply, and more rapidly than less meaningful stimuli (Craik & Lockhart, 1972). Another way that stimuli can be retained is through recirculating the information at one level of processing. The operation of holding the stimuli at one level of processing can be done through continued attention, and holding the items in rehearsal, and is termed 'primary memory' (Craik & Lockhart, 1972). The main feature of primary memory retention is that the stimuli is being constantly attended to. If attention is diverted from the item, information may be lost. Craik and Lockhart (1972) argue that there are three main sources of the failure of processing to reach the long-term stores level: the nature of the material, capacity availability, and task demands. The authors argue a set of orienting attitudes where rehearsal may strengthen the trace or merely postpone forgetting, but it will depend on what the learner is doing during rehearsal. Only deeper processing will lead to an improvement in memory (Craik & Lockhart, 1972).

Craik and Tulving (1975) suggest considerable modifications to the ideas suggested in Craik and Lockhart (1972), especially in their explanations of the depth of encoding. Craik and Tulving (1975) propose that the ‘spread of encoding’ may be a more satisfactory metaphor than depth. The depth of encoding describes that encoding operations are created in a fixed sequence and the spread of encoding refers to a more flexible idea that the basic perception of the stimuli can be elaborate in many different ways (Craik & Tulving, 1975). Morris et al. (1977) also suggest a need to reconsider assumptions of the levels of processing framework. The argument by Morris and colleagues (1977) is that shallow levels of processing may not be inferior to deeper levels of processing. It is possible that subsequent tasks that participants are asked to perform are not directly related to what was learned during acquisition. In this case, the idea that the processing level was shallow may be better explained by the inappropriateness of the relationship between acquisition and test. Morris and colleagues (1977) suggest that it may be useful to replace the concept of ‘levels of processing’ with ‘transfer appropriate processing’. Transfer-appropriate processing emphasizes the value of the acquisition activities relative to the goals. This concept of transfer-appropriate processing also suggests that it is no longer beneficial to assume that the memory traces are less adequate than others because those items were processed at a shallower level (Morris et al., 1977).

Over the years, work by Craik and Lockhart (1972) was criticized for the levels of processing framework being tautological. The criticisms come from the levels of processing that involve a tautology where deep processing is nothing more than a reiteration of better remembering (Lockhart, 2002). Lockhart (2002) compares this similar criticism and defence to Darwinian's natural selection where evolution by natural selection is also a tautology. The connection between levels of processing and natural selection shows that concepts like fitness or depth of processing can't entirely predict outcomes like survival or retrievability, they are more indicative of probability (Lockhart, 2002). Transfer-appropriate processing is used to describe a process that people undergo based on multiple factors related to the learner, the task, and the acquisition and transfer conditions. "The contribution of the transfer factor, if any, is less clear and therefore warrants further attention" (Lockhart, 2002, p. 400).

1.10.1.2 Pros of Generalizability

These theoretical perspectives in the generalizability of motor learning as demonstrated in transfer tasks bring many advantages to learners. One of the common conceptions about a transfer task is its use to validate generalizability as a learning criterion. Generalizability on a transfer task as an alternate learning assessment displays how practice on one task contributes to the performance of another task, perhaps in a different context. If there is evidence of performance improvement or maintenance on another novel task in the retention and transfer task, this motor skill generalizability demonstrates that the initial motor task from acquisition has been learned. In other words, evidence of motor skill generalizability in a transfer task can prove that the initial motor skill has been learned and can be used as analogous to the retention task outcome. Transfer-appropriate processing carries great benefits to ecologically valid (i.e., novel to activities of daily living/workplace/rehabilitation) applications. Many rehabilitation, workplace, or special population situations postulate that their intervention will create a motor task generalizability application to activities of daily living or other important skills.

1.10.1.3 Cons of Generalizability

While motor skill generalizability is generally viewed as a positive outcome of any learned motor skill, there remain issues with measurement and interpretations. Currently, there is no paradigm or process in place for selecting a transfer task. Depending on how similar the transfer task is to the initial task will have great implications on the amount of generalizability that will result. Woodworth and Thorndike (1901) proposed that transfer depends on the number of "identical elements" that are in common between two tasks. If the two tasks have vastly different elements, then no transfer would be expected. If the two tasks had mostly all their elements in common, then the transfer would be expected to occur. Where Woodworth and Thorndike (1901) are lacking, is in the specification of what is meant by "elements". This remains to be a limitation in the motor learning and transfer test literature, regarding creating appropriate transfer tasks and coming to appropriate conclusions based on the results.

1.10.2 The Specificity of Practice Hypothesis

The general dilemma of how to design a transfer test has great implications for the experience of the learner. In most situations, the transfer task aim is to be similar in some context to the initial task, to afford the learner the greatest chances of experiencing motor skill generalizability. This is not always the case, if the transfer task conditions employ a substantial shift in the dominant source of afferent information, learners may not have success on the transfer task, where the initial task was not beneficial to their transfer test performance. The ‘specificity of practice hypothesis’ is based upon the assumption that some motor skills are very specific and uncorrelated with one another and leaves the learner without motor skills that can be transferred (Barnett et al., 1973). This specificity of practice, sometimes called the specificity of training hypothesis, has been borrowed from the exercise physiology field (Barnett et al., 1973). In exercise physiology, specificity of training has been used in physical exercise and training to explain that if individuals want to improve their endurance performance in running or cycling, then they should train for the event at the same workload as the criterion performance (Barnett et al., 1973). The implication of this hypothesis in the exercise and training field is that the systems that are supporting the exercise are developed specifically for the different training intensities and that training is maximally effective when the training matches the performance intensity (Barnett et al., 1973). Borrowing this hypothesis from exercise and training has relevance to motor learning situations where motor skills are performed under distinct environmental, task, and individual constraints and conditions (Barnett et al., 1973).

1.10.2.1 Theoretical Perspectives in Specificity of Motor Learning

Three prevailing theories seek to explain why specificity of practice may exist in certain motor learning situations but not in others. These include practice contexts in which the learner develops task-specific sensorimotor representations of the movement parameters required to execute the task (e.g., Proteau, 1992, 2005; Proteau et al., 1987, 1998; Proteau & Isabelle, 2002) situations in which similar but effectively “new” movement patterns are required to successfully perform the new task (e.g., micromovements - see Starkes et al., 1993), and those contexts in which the knowledge structures underpinning successful task performance are changed or otherwise altered (Woltz et al., 2000). These theories tend to operate primarily at either a motor level or a cognitive level (or in some cases both). At a motor level, sensorimotor representations describe how motor learning is particular to how the task was initially practiced (Proteau et al., 1998).

Proteau (2005); Proteau and colleagues (1987, 1992, 1998); Proteau and Isabelle (2002) have tested the specificity of the practice hypothesis through the manipulation of with and without full vision and consistently have found findings supporting the specificity of the motor practice hypothesis. In 1987, Proteau and colleagues tested the theory of sensorimotor representations through the amount of practice (i.e., 200 or 2000 trials) and the amount of vision that was available (i.e., limb and target, or target only) by extinguishing the lights in the room and allowing the target to illuminate. The motor task used a stylus to reach a target from a defined starting position using the non-preferred left hand and was instructed to complete the task in a movement time of 550 milliseconds. As one would hypothesize, in the acquisition, the limb and target vision group had superior performance (measured by root mean square error) on the motor task regardless of the number of trials. All groups underwent a transfer test where participants performed under the condition of target-only vision. In the instances where participants underwent 2000 trials, the limb and target group experienced a decrement in motor performance when transferring to a target-only condition. These results indicate that having a vision of the moving limb adds important information to the movement control process that allows the participant to be more accurate than if the vision of the limb was not present. In this experiment by Proteau and colleagues (1987), movement-relevant information that is intrinsic to the task and participant results in motor learning based on a sensorimotor representation that is specific to the learned task.

The work of Proteau and colleagues (1992) continues along this specificity of practice story and extends upon their previous work on the basis that movement learning is a sensorimotor representation. Proteau and colleagues (1992) used a similar task to Proteau and colleagues (1987) with the addition of having their movement perturbed during its course which required participants to learn to compensate for the applied perturbation. The motor task used by Proteau and colleagues (1992) also included using a stylus at a starting location and moving to the target in 550 milliseconds. The amount of practice in this experiment involved either 200 trials or 1200 trials and the amount of vision was manipulated by having either a limb and target vision group or a target-only vision group. The transfer test involved all groups performing the task under the limb and target vision condition. The group that had been performing with 1200 trials and in the target-only condition throughout acquisition experienced an increase in root mean square error of their motor task in a transfer test when the vision of the ongoing limb and surrounding environment were permitted. This increase in error was not also seen in the

200-trial group, demonstrating that this specificity effect is developed over substantial practice. These results differ from the previous Proteau and colleagues (1987) experiment where removing relevant sensory information that was utilized during acquisition and having decreased performance. The Proteau and colleagues (1992) experiment showed a group that had practiced a motor task with minimal sensory information, and when given additional relevant sensory information, the additional use of vision interfered with what had been learned, resulting in a decrease in performance. The results show that the addition of vision in a transfer test exacerbates its dominance as a source of information and results in participants attending to the vision and neglecting the basis on which the motor task was originally learned (target only).

By way of another example, Proteau and colleagues (1998), used a 2.5cm wide 20m precision walking task to examine the specificity of the different conditions under which participants practiced, (i.e., 20 or 100 trials, and under normal vision or blindfolded). Following each walking trial, all participants received the knowledge of results; that is, they were provided with their movement time as the target bandwidth was between 14-16 seconds to complete the task. Participants in the full vision condition were able to visually evaluate their spatial and temporal accuracy on each trial. To include similar knowledge of results for both groups, participants in the blindfolded condition lifted their blindfolds at the end of each trial. Following the acquisition, all participants performed 20 trials of the task under the condition of being blindfolded and without knowledge of the results feedback. The results revealed a significant interaction between the visual feedback conditions and the levels of practice. The interaction reveals similar root mean square errors (RMSEs) for the participants who underwent training for 20 trials in either the full vision or the no vision conditions (2.04m and 2.15m, respectively). The participants that trained for 100 trials in the full vision condition had significantly more errors in transfer than any other group (Proteau et al., 1998). These results from Proteau and colleagues (1998) support the specificity of practice hypothesis in that the full vision 100 trial group relied heavily on visual information for movement control, to the detriment of any other source of sensory information (i.e., kinesthetic). Stated differently, the lack of generalization demonstrates motor performance that is limited to a specific sensorimotor representation (i.e., in this case, limited to full vision).

Proteau and Isabelle (2002) investigated whether the specificity of practice hypothesis was mediated by the importance of visual afferent information for the control of manual aiming movements and how motor learning is affected by the withdrawal of visual information in a transfer test. The motor task used an arm manipulandum with participants sitting at a table and looking at a computer screen. The motor task was to try to stop the cursor on a target having a diameter of either 4 millimetres or 50 millimetres and to complete the movement between 480-620 milliseconds. Each participant was randomized into one of four experimental groups that differed by target size (4mm or 50 mm) and visual information available (full vision or target-only vision) and performed 200 trials in acquisition. All groups regardless of which vision condition they were in became more accurate, less variable, or both as a function of practice across acquisition. All participants completed this acquisition phase as well as a transfer test where all groups performed the motor task in the target-only vision group. Of interest in this experiment was that the group trained in an acquisition under the condition of full vision experienced the greatest decrement in motor performance with the greatest amount of error compared to the target-only group in the transfer test to target-only vision. This suggests that participants in the full vision group were only able to complete the motor task with success under the sensorimotor representation that they practiced. Any deviations from this sensorimotor representation of having full vision was appearing as a new motor task with difficulty, not as a motor task that they have previously practiced and gained experience on.

Another prevailing theory as to why the specificity of practice exists at the motor level is the idea of new movement patterns (Starkes et al., 1993). The first study mentioned in their chapter (Starkes, 1993) examined an oral surgeon throughout a five-day course in microsurgery. The course involved the surgeon to progress in the difficulty of materials starting with suturing a glove material, to an artery, and finally a vein. The surgeon was timed how long it took to perform each suture because the more efficient a surgeon becomes, the less time it will take to perform each maneuver. On day one, the surgeon takes 45 minutes and 36 minutes to complete the glove material sutures in the morning, and by the afternoon, the surgeon takes 3.5 minutes. On day two with the artery suture, the surgeon takes 13 minutes. Each day thereafter, the surgeon's movement time decreases. This case study explains the surgeon's day-one performance on the glove material to show a negative transfer effect from previous oral surgery experience. The wrist movements involved in the oral surgeon's typical procedures must now be inhibited and a new movement pattern is used to complete the new task early in learning. Once the new movement patterns are in place, efficiency improves of the movements (shown by the afternoon on day one).

A second study (Starkes, 1993) compared the performance of three surgeons with varying levels of expertise (i.e., one had just completed the course, an intermediate-level surgeon who had been practicing for three years, and a world-renowned surgeon with many years of experience). This study examined the time to completion from needle insertion to completion plus tie-off and the suture is cut. The surgeon who had just completed the course took 209 + 87 seconds to complete each suture, the intermediate surgeon took 74 + 24 seconds, and the expert took 38 + 12 seconds. These results suggest that the expert surgeon performed the best and provides the most efficient surgeries with minimal tissue trauma and lower time under anesthetic for the patient. This directly relates to motor skill generalizability as the previous experience catalyzes the next skill to experience such success.

A study by Allard and Starkes (1991) recruited the intermediate-level surgeon and examined the separation from “knowing” and “doing” and established new links with alternative “doing”. The study hypothesized that if individuals can forge new knowing and doing links, perhaps they also can have a skilled performance from currently existing elements even when the elements are unrelated and have never been performed together. The intermediate-level surgeon was asked to perform a handwriting task in a different sensory context (high microscopic magnification) to investigate this. She was asked to write her name, along with “gentry”, “dactyl”, and “ingot” as lower-used words at magnifications of 16X, 25X, and 40X and these samples were compared to her regular handwriting. Although she had never written under high magnification, she has written before, and she has performed sutures under high magnification, giving her the tools to adapt to perform micro writing. By combining her existing elements of experience, or “knowing” and “doing”, the novel skill of micro writing was possible. This chapter by Starkes and colleagues (1993) suggests that prior surgical experience can influence performance on a novel task and create negative transfer early in learning. This chapter also discusses observations of the course instructors mentioning that oftentimes students with no prior surgical experience have an easier time learning movements in the early stages of the course than more intermediate-level surgeons.

Both the research by Proteau and colleagues (1998) and the chapter by Starkes and colleagues (1993) suggest the original practice condition (or expertise) created interference in the new sensorimotor contexts. At a more cognitive level, Woltz and colleagues (2000) discuss the concept of processing sequence knowledge structures by describing how practiced individuals will favour familiar (even if more complex) solutions. In experiment one, participants were asked to solve four-digit problems that required three-rule sequences. For example, 3213 would be reduced to 113 by applying the different rule to the first two digits (i.e., 32 = 1). Then, 113 would be reduced to 13 by applying the same rule (i.e., 11 = 1). Third, 13 would be reduced to 2 by applying the different rules. This example was solved using what the authors termed the different-same-different rule sequence. In the experiment, participants in two groups solved 6 different sequences using the different-same-different rules with one group receiving more practice before transfer trials than the other group. Both groups received the same instructions regarding the sequence rules, however, one group received five times as much practice in applying the rules. In the transfer test, two new sequences not seen in training were added. The researchers hypothesized that the stronger memory for processing the rule sequenced used in training would result in performing incorrect responses in the final transfer test problems. The results of this experiment supported their hypothesis that the error rate was greater for the highly trained group. These results suggest that more practice in a sequential cognitive task leads to negative transfer when a new sequence resembles but is different from the practiced task.

In experiment two (Woltz et al., 2000), three additional questions were investigated with a similar structure to experiment one. First, the researchers tested whether the negative transfer errors observed in experiment one could be produced in a more complex skill that involved practicing many processing sequences. Second, whether the errors were attributed to sequence knowledge or instance knowledge. Third, the degree to which the errors were detectable by participants was examined. The task involved the presentation of any combination of the numbers 1-9 and the participant had to reduce the digits into a single digit based on applying the sequence rules. The same rule involved reducing two identical numbers into a single number (e.g., 77 = 7). The midpoint rule is to reduce different numbers into their midpoint (e.g., 53 = 4). The contiguous rule states that two numbers in an ascending or descending pattern could be reduced to the next number in the sequence (e.g., 67 = 8). The last rule states that two numbers whose difference is greater than two could be reduced to the last of the two numbers (e.g., 28 = 8). Like experiment one, two groups were involved in the learning of this cognitive task, and one group received more practice on the task before the transfer test (i.e., the low-skill group received one session of practice, and the high-skill group had four sessions of practice). The transfer test involved 12 new sequences not seen in practice with familiarity being that each new sequence matched an old sequence in the first two component rules but ended with a different rule. The results of this experiment revealed an overall difference in transfer trial latencies with the high-skill group's performance being faster than the low-skill group. Results for the errors made revealed the high-skill participants made more errors in the new sequence transfer test than the low-skill group, and went undetected, as hypothesized. Woltz and colleagues (2000) explain these outcomes with a ‘strong-but-wrong’ slip phenomenon where both rule-based and skill-based performance modes can result in negative transfer from inherent cognitive tendencies of similarity matching (i.e., incorrectly matching new conditions because they resemble familiar conditions) and frequency gambling (i.e., defaulting to high-frequency responses). The authors acknowledge this strong-but-wrong theoretical description was based on anecdotal evidence, and its existence in experimental research is yet to be adequately tested.

Although Woltz and colleagues (2000) examined cognitive tasks in multistep skills, rather than motor tasks, the theory can apply to motor tasks as well. Woltz and colleagues (2000) use ‘knowledge structures’ to explain why sometimes there is generalizability, and why sometimes there is a specificity of skills, though the latter is much rarer. Their theory suggests that new task conditions that normally lead to generalizability can lead to poor transfer if the processing sequence knowledge is triggered inappropriately (Woltz et al., 2000). One explanation for why this may occur is through a lack of error detection and correction. If the transfer errors are outside of a participant's awareness (e.g., in multistep skills), they can sometimes go by undetectable to the participant, leading an otherwise expert participant with worsened performance. Another explanation for the specificity of practice hypothesis from a cognitive perspective is the Einstellung effect demonstrated experimentally by Luchins (1942). In this experiment, Luchins (1942) gave participants a series of problems that could be solved by a fixed method which they quickly learned. Then, the participants were given a new problem that appeared like the rest but could not be solved in the way that they had previously been doing. The fixation on this new problem and thinking it was insoluble was evident when compared to participants in a control group that did not receive the previous method of performing the task and were able to solve the problem. The control group solved the new problem quickly, showing that the problem was solvable, whereas the experimental group was not able to solve the problem because of the similarity of the problem to the previous questions, preventing the experimental group from considering any alternative problem-solving methods. This is known as the Einstellung effect, where the first idea that comes to mind (triggered by familiarity), prevents a better solution to be found. This is important in cognitive learning domains where the first schema that is activated by familiar aspects controls the learner's subsequent direction of attention and can contribute to a bias in problem-solving thoughts. This effect should be kept in mind in the application of motor learning domains as well.

1.10.2.2 Pros of Specificity

Motor skill specificity tends to present more disadvantages to learners compared to motor skill generalizability which poses more advantages in an individual's everyday living. Where motor skill specificity is important in the emergence of especial skills. Especial skills refer to specific, highly proficient skills defined as "a result of massive amounts of practice, has a special status within a generalizable class of motor skills, and which is distinguished by its enhanced performance capability relative to the other members of the same class" (Keetch et al., 2005, p. 976). For example, the basketball free-throw 15-foot line is a highly practiced set distance for basketball players that has no other advantage aside from expertise due to the enormous amounts of practice.

1.10.2.3 Cons of Specificity

The disadvantages to motor skill specificity are more severe than any disadvantages outlined in the generalizability of learning motor tasks. Not only can motor skills not transfer to a new motor task, but there could be a significant decrement in performance as a function of having practiced a previous motor skill. For example, by owning a car, one may become very comfortable with their car's design and location of all its features. If that same individual were to rent a car that has features in different locations from what they are used to, (e.g., the turn signal is in the location of the windshield wipers, and vice versa) they will likely make several errors. These errors are present and amplified because the individual previously learned how to use the car features on their own car first. Without prior knowledge of how to operate their car first, the rental car would appear as a new task, without the obstacle of having these predispositions. Ecologically valid situations do not practically benefit from specificity of practice or detriment in performance outcome. In the rare instances where the intention is to have motor task generalizability, and the outcome is motor task specificity, there is currently no framework to aid in the prediction of these outcomes. In their 2005 chapter, Schwartz and colleagues (Schwartz et al., 2005), delve into the complex landscape of transfer research, highlighting the many divergent viewpoints that characterize this area of study noting, "the transfer literature includes a variety of seemingly conflicting perspectives" (p. 1). Despite their primary focus on cognitive processes, the parallels drawn between cognitive science and motor learning are apparent. The authors discuss in detail the inconsistent claims throughout the literature on transfer, addressing the abstract nature of the concept of 'transfer' itself. Furthermore, Schwartz and colleagues introduce a comprehensive framework designed to bridge the gaps between these differing perspectives on transfer. This framework not only sheds light on the underlying complexities but also offers a path toward a more integrated understanding of how transfer operates across both cognitive and motor domains. This is, as well, the goal of this thesis. In conclusion, the specificity of practice has serious implications for negative motor skill performance. Currently, there is no review to demonstrate which sort of motor skills exhibit generalizability, and on the contrary, which sort of motor skills are more likely to reveal specificity of practice.

CHAPTER 2: A SCOPING REVIEW AND TAXONOMY OF THE SPECIFICITY OR GENERALIZABILITY OF LEARNING A MOTOR TASK

2.1 Abstract

There is a gap in the motor transfer test literature related to any systematic process of classification or the categorical language of tasks commonly generalizable in transfer versus those that are specific to the learner’s original sensorimotor experiences. Without a systematic process, researchers lack useful, if not fundamental, information regarding if or how motor skills transfer to different tasks and what mechanisms of motor skill acquisition lead to flexibility in learning. The objectives in this chapter are: 1) To survey systematically peer reviewed literature that report experimental results involving transfer test measures; 2) To categorize the transfer test results to support or refute notions of specificity or generalizability of practicing a motor task, evaluated as positive transfer, negative transfer, neutral transfer, or mixed results; 3) To develop a taxonomy that will offer a common framework for exploring and contextualizing the relative specificity or generalizability of motor skills by providing a structure to develop and utilize more consistent language and terminology, use transfer testing protocols that are appropriate for the context and goals of their experiments, and for cross-comparing research studies that employ different motor skill transfer protocols; 4) To determine if there exists any commonality between the taxonomy and transfer test outcome that points toward motor training protocols that are more likely than not to lead to generalizability or specificity of practice. The search consisted of Medline, Embase, PsychINFO, PubMed, Web of Science, Sport Discus, Cumulated Index to Nursing and Allied Health Literature

(CINAHL), and ProQuest occurred from inception to March 2020. Three independent reviewers screened all texts using Rayyan Qatar Computing Research Institute (QCRI). The results were pooled to categorize experiments into the degree of transfer and component being transferred. From the 1266 articles identified, 135 articles met full inclusion criteria and were included in the analyses. Of the 135 included experiments, 36% resulted in positive transfer, 25% resulted in neutral transfer, 25% resulted in mixed results, and 14% reveal a true specificity of practice effect. The 135 studies included in this review produced Tuckey's Ten Transfer Taxonomies. From the taxonomy, little commonalities were found between studies that resulted in motor learning generalizability or specificity. From the 1266 studies identified, many of these studies were excluded for reasons that may be avoidable in future motor learning experiments with the intent to test for motor skill generalizability. Specificity of practice is the rarest outcome when attempting to transfer a previously acquired skill. Using the operationally defined taxonomies that are developed in this thesis, we can get a better understanding of the commonalities between some of these rare instances, however, the results reveal many inconsistencies both between and within research disciplines.

2.2 Introduction

2.2.1 Definitions of Terminology

The generalizability of training has been defined by Krakauer and colleagues (2006) as the ability to apply what has been learned in a previous context to another context, typically assessed in motor learning using a 'transfer' test. In reference back to the chapter by Schwartz and colleagues (2005), they outline how the term 'transfer' with standard definitions relates to the degree that a behaviour will be repeated, which is not all-encompassing enough. Their chapter added to the standard transfer definition by adding "preparation for future learning" (Schwartz et al., 2005, p. 5). We agree that the term 'transfer' is nebulous, and requires further investigations. First, the 'transfer' type of results are outlined below. In motor learning research, generalizability can be measured using a transfer test with a positive transfer result. A positive transfer result is represented by a significant improvement in the performance of the outcome of interest in the second context (e.g., improvement in movement time, improvement in the number of errors, etc.). The term specificity of training originates from exercise physiology and can be defined as when the training program stresses the physiological systems that are critical for optimal performance in the given activity (Wilmore & Costill, 1994). In the motor learning context, the definition is similar where at the base of movement learning is a sensorimotor representation. When this sensorimotor representation is changed, there is a large movement decrement (Proteau et al., 1992). This can also be measured using a transfer test, except this time with a negative transfer result. A negative transfer result is represented by a significant decrement in the performance of the outcome of interest in the second task (e.g., deterioration in movement time, deterioration in errors made, etc.).

A third outcome of a transfer test is to have neither a significant improvement, nor a significant decrement in performance, resulting in neutral transfer from the movement acquisition to the transfer test. This outcome suggests that the movement acquisition does not affect the transfer to the second motor task. A transfer test result with neutral transfer is also a form of specificity of training as the initial motor task has specific sensorimotor representations that are not usable in the transfer task. While a transfer test that results in neutral transfer from acquisition has support for the specificity of training principle, there is also the ambiguity of a no-change transfer test that suggests the transfer task is unrelated to the acquisition task and seen as a new task to the individual. The studies that result in neutral transfer in the transfer test are seen as a neutral outcome that had neither a positive nor a negative outcome on the transfer task.

Though a transfer test with neutral transfer shares a theoretical basis with a specificity of training, it is not the strongest form of specificity. The strongest form of specificity of training is represented by a negative transfer result in a transfer test. Throughout this chapter, the concept of generalizability will include studies that have a transfer test with a positive transfer outcome. To extrapolate the strongest form of specificity, this chapter will consider ‘specificity of training’ or ‘specificity of practice’ as the studies that result in a negative transfer outcome in the transfer test.

2.2.2 Generalizability of Motor Learning

A historical review of the research on the transfer of motor skills was conducted by Adams (1987) who outlined perspectives on practice, retention, and transfer. Adams (1987) describes why researchers use transfer tests, which are to make inferences about basic behavioural mechanisms, as how training on one stimulus transfers to another as a means of determining generalization. Adams (1987) describes the transfer literature as having a mix of tasks and findings, making it difficult to see generalizations.

Since then, there are more recent reviews that have a transfer of motor skills as the focus but have a narrower focus on the types of studies included such as virtual reality

(Levac et al., 2019), and in physiotherapy settings (Sattelmayer et al., 2016). Levac and colleagues (2019) conclude that virtual environments should enable transfer from therapeutic practice to real-world settings. Sattelmayer and colleagues (2016) examined part or whole practice, random or blocked practice, mental practice, and terminal or concurrent feedback applied to physiotherapy and medical education settings. This systematic review concludes with mixed results that there was some evidence to recommend the use of mental practice in medical education, limited evidence to conclude that terminal feedback is more effective than concurrent feedback, and insufficient evidence in the remaining parameters that were reviewed to make definitive recommendations (Sattelmayer et al., 2016).

2.2.3 Specificity of Motor Learning

Previous work has been conducted to review the literature to support the specificity of motor learning but in smaller sections. Provins (1997) reviewed the specificity of manual motor skills and the manual asymmetries that come with handedness and proficiency differences between two limb sides. Provins (1997) attributed the specificity of movements as it relates to hand usage to habitual hand usage, which leads to proficiencies on one side.

Oppici and Panchuk (2022) conducted a systematic review of the specificity and generality in the context of sport. These authors proposed a specificity-generality continuum for sports that may not have as clear of outcomes as laboratory-based experiments where a transfer test can result in either clear specificity or generalizability. Oppici and Panchuk (2022) used an ecological perspective as a factor that influences motor skill specificity or generalizability where perceptual-motor transfer emerges along the specificity-generality continuum based on the individual's current motor skill repertoire. The authors suggest that expert athletes showed a higher magnitude of transfer than novices because of their superior ability to perceive similar affordances in different sports, which drove their ability to transfer skills (Oppici & Panchuk, 2022). A repertoire of previous experiences and the requirements of a new motor task are continuously interacting and shaping the performance and learning in a transfer task (Oppici & Panchuk, 2022).

2.2.4 The Gap in the Literature

Currently, there is no all-encompassing, general review that we have found that serves to display the generalizability and/or specificity of different motor tasks. While there are individual studies that speak to motor learning generalizability and/or specificity, these results have yet to be compiled into a comprehensive single review or meta-analysis. As such, little is currently known about which type of learnable motor skills are likely to generalize better than others to different motor skills or performance conditions, and/or which learnable motor skills are likely to be so specific to the conditions under which they were practiced that there is reliable evidence of negative transfer. As Adams (1987) suggested over 35 years ago there is a mixture of tasks and findings in the transfer literature and this gap in the literature makes it difficult to see generalizations.

2.3 Research Questions

Therefore, the purpose of this scoping review is to map existing literature on transferring motor task skills from a previously acquired task to a new task or skill. More specifically, the aim of this scoping review is:

1) To survey systematically peer-reviewed literature that reports experimental results involving learning a motor task with transfer test measures.

2) To categorize the transfer test results to support or refute notions of specificity or generalizability of learning a motor task, evaluated as positive transfer, negative transfer, neutral transfer, or mixed results.

3) To develop a taxonomy that will offer a common framework for exploring and contextualizing the relative specificity or generalizability of motor skills by providing a structure to develop and utilize more consistent language and terminology, use transfer testing protocols that are appropriate for the context and goals of their experiments, and for cross-comparing research studies that employ different motor skill transfer protocols.

4) To determine if there exists any commonality between the taxonomy and transfer test outcome that points toward motor training protocols that are more likely than not to lead to generalizability or specificity of practice.

2.4 Methodology

2.4.1 Study Design

A scoping review was designed to identify studies that focus on motor learning experiments that employ transfer tests to evaluate either a generalizable or task-specific motor learning outcome. The overall approach of this scoping review closely follows the Preferred reporting items for systematic review and meta-analyses (PRISMA) guidelines for scoping reviews (Tricco et al., 2018). An a priori protocol was developed in advance under the guidance of two McMaster Health Science librarians using the Preferred Reporting Items for scoping reviews (PRISMA-ScR Checklist, see Appendix A).

2.4.2 Search Strategy

Once the research question had been determined and operationally defined (see below), meetings occurred with two of McMaster University's Health Science librarians to develop an appropriate Boolean search strategy to use, adapted to each database, and identify which databases would be most appropriate to use. The search strategy was designed to capture studies with any motor task, evidence of learning, and a transfer element (See search strategy in Appendix B). An electronic search was conducted using the following databases: Ovid – Medline, Ovid – Embase, Ovid – PsycINFO, PubMed, Web of Science, EBSCO host – Sport Discus, EBSCO host – CINAHL, and ProQuest – ERIC on March 20, 2020, from database inception.

2.4.3 Inclusion/Exclusion Criteria

All original primary quantitative research studies (e.g., cross-sectional, randomized controlled trials, cluster randomized controlled trials) using a) any motor task, b) required evidence of learning, and c) included a transfer test were eligible for inclusion. Studies also must have been written in English and published in a peer-reviewed journal.

2.4.4 Sources of Evidence Selection

During the title/abstract screening, the following criteria were used:

1. Does the title/abstract involve the learning of a motor skill?
    a. Must be a motor task (i.e., can be serial, discrete, continuous, gross, fine, temporal, spatial, force production, or any combination of these)
    b. Must not include the learning of any non-motor tasks (e.g., learning of languages)
2. Does the title/abstract describe a specificity or generalizability of practice experiment?
    a. Study alludes to the use of a transfer test, application to other tasks, generalization to a different task, or the specificity of the task

Title and abstracts were screened by three reviewers using Rayyan QCRI reviews web application. Each reviewer contributed a vote towards including the study (i.e., ‘Yes’), excluding the study with a note explaining the reasoning why (i.e., ‘No’), and flagging the study for questioning and further examinations (i.e., ‘Maybe’). Disagreements between reviewers were resolved through discussion. If the conflict conversation left the reviewers in indecision, then the article was sent to a fourth reviewer (JL) for a final decision.

After title/abstract screening, articles were reviewed at the full-text stage, which was screened against the above criteria, in addition to the third question:

3. Does the study report a retention/transfer test with a duration of at least 24 hours following the initial acquisition phase to include consolidation of the skill?

2.4.5 Data Extraction

The details extracted from the included studies are based on a priori decisions. Specific methodological details that were reviewed included: article title, year, author(s), participants, groups (if more than one), participant demographics, motor task(s), main measure(s), retention test duration, transfer test task and duration, type of transfer, main finding, and degree of generalizability or specificity.

Studies were only represented once each in the data analysis, even if a study could have multiple types of transfer included. Tiebreaker decisions were given based on whether the article weighted more emphasis on the primary aim of the study (e.g., one of the main aims of this article was to examine the effects of constant and variable practice, making the condition of practice more important on the transfer test than the target shift). This decision was made by the principal investigator.

2.5 Results

2.5.1 Objective 1: Survey of Generalizability and Specificity

The initial search from all databases yielded 1266 articles, leaving 940 studies after duplicates were removed. After title and abstract screening, 597 articles did not meet the inclusion/exclusion criteria. Fifty-seven articles were removed after full-text screening for the wrong type of experiment and/or wrong type of publication and 133 articles were eliminated for having a less than 24-hour retention test duration, leaving a total of 135 articles included for analyses (see Figure 2.1 for the Flow Diagram PRISMA-ScR). A full reference list of all included articles is available in Appendix C-F.

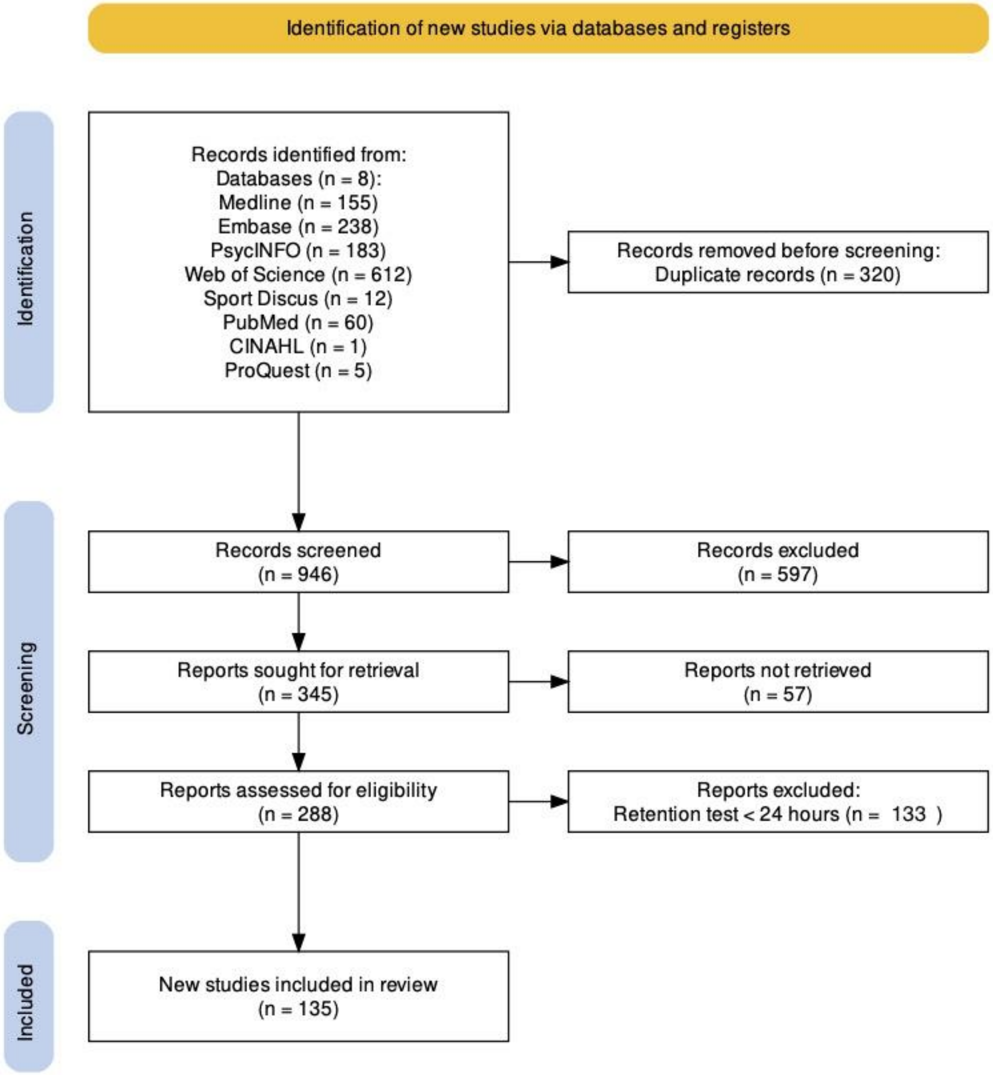


Figure 2.1: Flow Diagram PRISMA-ScR

Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimized digital transparency and Open Synthesis Campbell Systematic Reviews, 18, e1230.

2.5.2 Objective 2: Categorize into Positive Transfer/ Negative Transfer/ Neutral Transfer/ Mixed Results

Each article included in this scoping review was given a degree of generalizability or specificity with four possible outcomes: positive transfer, neutral transfer, negative transfer, or mixed results. Of the 135 articles included in this scoping review, 36.3% (n = 49) provide evidence of positive transfer, 25.19% (n = 34) provide evidence of neutral transfer, 24.44% (n = 33) provide evidence of mixed results, and 14.07% (n = 19) provide evidence of negative transfer.

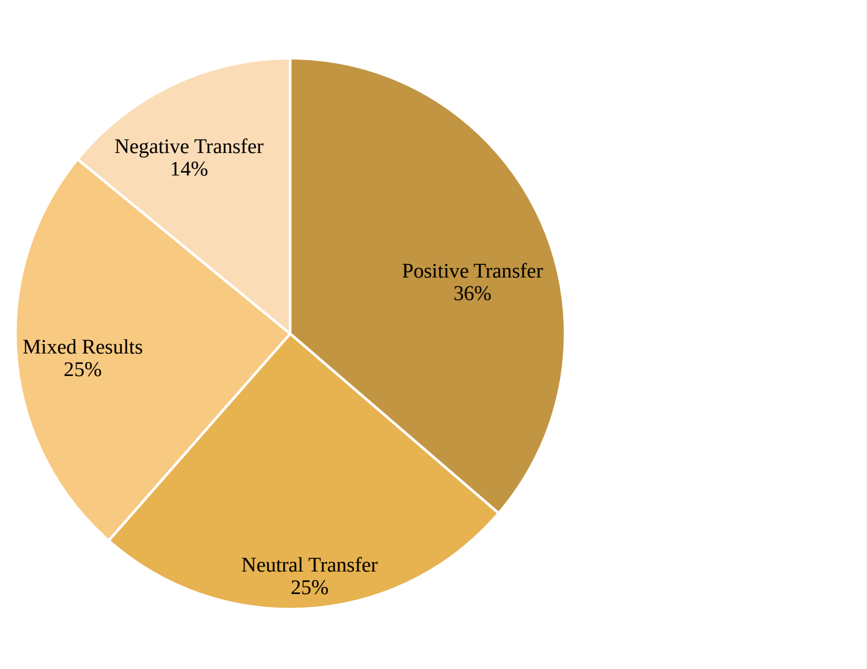


Figure 2.2: Amount of generalizability or specificity included in this scoping review represented by four possible outcomes including positive transfer, neutral transfer, negative transfer, or mixed results.

2.5.3 Objective 3: Taxonomy

Based on filtering these articles into categories to help interpret the main types of transfer, broad categories were created as a starting point. There were an initial 12 categories with operational definitions used as stated in Table 2.1.

Table 2.1: Initial 12 categories created the basis of the scoping review taxonomies that were later pared down to only 10 categories

Initial 12 categories	**Operational definitions**
Ecological validity transfer	Novel task acquisition to workplace specific task [e.g., peg transfer to laparoscopic skill]
Anthropometrical transfer	When task acquisition occurs with one specific body part or limb and is transferred to an alternate body part or limb
Target/task transfer	Novel task acquisition with change in target/goal in its temporal/spatial components [e.g., target shape change]
Conditions of practice transfer	Schedule order randomized for transfer test
State transfer	Physical condition of participant is manipulated for transfer
Healthy to compromised within participant transfer	Skill is acquired on healthy limb/hand and transfer is assessed on paretic limb/hand
Unimanual/bimanual transfer	Task acquisition performed unimanual/bimanual, then switches to opposite for transfer

Expertise transfer	Previous skill or expertise brought into the study to test transfer to a novel, similar, or especial skill
Atypical versus neurotypical	Individuals with an atypical neurological /physical disability transfer of skills compared to a neurotypical control group
Feedback modality transfer	Task remains the same, but the feedback modality given is transferred to a different modality of feedback
Motor imagery transfer	Motor imagery used to practice, transferred to real setting
Virtual environment transfer	Task acquisition performed in a virtual environment and transferred to real environment

As this review progressed, some of these categories from the initial classification were identified as being more niche than others. That is, a category may have had only one article populating it and thus could be described in a broader sense to include other articles as well. To provide separate categories, the following categories were combined or adapted. ‘Healthy to compromised within participant transfer’ and ‘atypical versus neurotypical’ were removed, and atypical, rehabilitation, and special populations were noted in the demographics, and the motor task and transfer test were categorized regardless of the demographic group. The category ‘motor imagery transfer’ also evolved throughout the reading for the review, and sub-categories of ‘instruction transfer’ and ‘focus of attention’ were added to include studies that manipulate instruction vs. no instruction groups, or internal vs. external focus of attention groups. ‘Motor imagery transfer’ with the subcategories was collapsed into ‘attention transfer’ to capture all studies that focus on the thought processes of participants (see taxonomy).

To be better able to interpret why some experiments reveal effects for specificity of practice and some experiments reveal effects for generalizability, these taxonomies were created to determine if certain types of experimental designs are more likely to reveal positive transfer, neutral transfer, or negative transfer effects. Outlined below are ‘Tuckey’s Ten Transfer Taxonomies’ with an operational definition/description and an example of the types of experiments in each. These taxonomies are designed to create transfer test categories to appropriately organize what type of transfer is occurring. Additionally, each article (n = 135) was matched with a taxonomy category to describe the main type of transfer occurring (Figure 2.3). Out of the 135 articles meeting all inclusion criteria and thus included in this scoping review, target/task transfer represents 16.3% (n = 22), conditions of practice represents 14.81% (n = 20), expertise represents 14.81% (n = 20), feedback modality represents 14.81% (n = 20), anthropometrical represents 13.33% (n = 18), equipment represents 8.15% (n = 11), ecological validity represents 5.19% (n = 7), attention represents 5.19% (n = 7), state represents 4.44% (n = 6), and virtual environment represents 2.96% (n = 4) studies included in this scoping review and are displayed in Figure 2.3 and Figure 2.4.

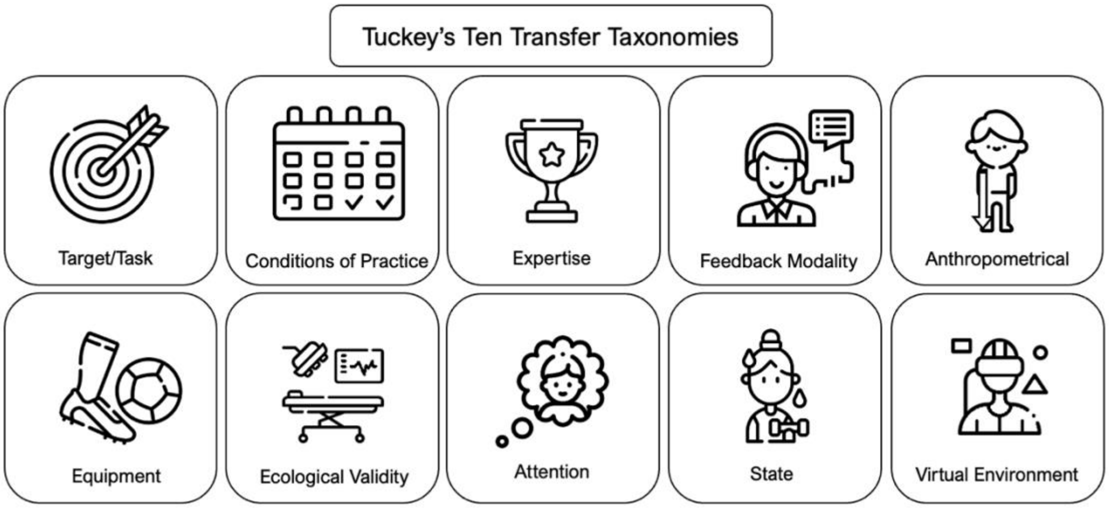


Figure 2.3: Tuckey's Ten Transfer Taxonomies

Target/Task Transfer: This category (n = 22, 16.30%) can be described as where an element of the task or the goal/target changes. This could be a timing/spatial/force production goal change in the transfer test. An example of this category is learning a bean bag throwing task and having a transfer test of throwing the bean bag to a new target (Jarus & Goverover, 1999). Another example of a task/target transfer includes an experiment by Meira and Fairbrother (2018) where they compared high-ego-oriented vs. low-ego-oriented students standing on a stabilometer task. Their transfer task was to switch to a new stance position.

Conditions of Practice Transfer: This category (n = 20, 14.81%) is where a practice schedule element changes from the acquisition is assessed in transfer (for example, contextual interference or pacing studies). An example of this category is a classic contextual interference style of an experiment where there is one group in an acquisition that trains with a blocked schedule of practice, and the other has a random schedule of practice. For the transfer test, groups switch the condition of practice that they trained under (e.g., King & Newell, 2013) An example of a pacing experiment in this category is from Nystrom and colleagues (1953) that examined self-paced vs. automatically paced responses in a keyboard response task, where in the transfer test, groups switched pacing conditions.

Expertise Transfer: This category (n = 20, 14.81%) is different from the other categories as participants are coming into the experiments with a previously acquired skill/expertise. For these experiments, no acquisition, nor retention test are needed, just a transfer test. These types of experiments assume that learning has occurred outside of the experiment and the previous experience acts as the acquisition and retention. This would include, for example, experiments with athletes, surgeons, and pilots. An example of an experiment in this category would be by Czyż and colleagues (2013) where basketball players with previous sports experience were assessed at various free throw shot distances. In this case, the free throw shot distance that the basketball players typically shoot from acts as the retention test and the atypical shot distances act as a transfer test.

Feedback Modality Transfer: This category (n = 20, 14.81%) can be described as where the task remains the same, but the sensory modality (e.g., audition to vision) in which feedback is given differs. An example of an experiment in this category would be having a full vision group and a target-only illuminated group during a motor learning task, and then transferring to the other feedback condition in the transfer test (Bennett et al., 1999). Another example of a feedback modality transfer experiment is from Toussaint and colleagues (2017) who had one group of students perform a leg flexion task with vision and proprioception, and the other group perform the task with only proprioception. Both groups then switched to the proprioception-only condition which serves as a retention test for the initial proprioception group and a transfer test for the vision and proprioception group. Unfortunately, this is one of the many experiments that had their retention test less than 24 hours from acquisition (10-minutes) and is therefore excluded from this scoping review on that basis.

Anthropometrical Transfer: Types of experiments in this category (n = 18, 13.33%) can be operationally defined as where task acquisition occurs on one limb and transfer is assessed on another limb. Examples of this classification would include rehabilitation, healthy to paretic limb experiments, and unimanual/bimanual combination experiments. For example, learning a gait pattern on one leg, and assessing how much of that skill was able to transfer to the other leg (Krishnan et al., 2018).

Equipment Transfer: This category (n = 11, 8.15%) is defined as where the task remains the same but the equipment changes. Examples of different equipment used are ball size/weight change, mouse to button, or beanbag to a horseshoe. An example of an experiment in this category is a study that used bean bag tossing as their motor learning task and switched to horseshoe throwing for the transfer task (Dick et al., 2000a).

Ecological Validity Transfer: Types of experiments in this category (n = 7, 5.19%) can range from workplace simulators to real workplace tasks, or from an activity of daily living task deconstructed into a laboratory novel task, and then transferred to the actual activity of daily living task. An example of ecological validity category from a workplace would be using a training simulator with a direct view in practice and switching to an endoscopic view in a transfer test (i.e., to more appropriately assess performance during a standard surgical view (Heuer et al., 2012). Other versions of this category come from “activity of daily living” research. An example of this kind of ecological validity experiment is from Jo and colleagues (2020) where they examined one group under blocked practice comparing another group under random practice with the motor task of spooning stones. The transfer task was then to switch participants to spooning cornflakes as the more ecologically valid version of that motor task. In this type of experiment, it is important to dissociate the methodology element of blocked vs. random practice. which will be discussed in the ‘Conditions of Practice’ category later in this manuscript, from the element that is being transferred in the transfer test. The element that is being transferred in the transfer test, and the main objective of that experiment, is to examine the ecological validity of spooning stones into spooning cornflakes.

<u>Attention Transfer</u>: This category (n = 7, 5.19%) represents experiments where a specific thought process via instructions or motor imagery is used in the acquisition and transfer is assessed in a real environment or other instructions. This contains subgroups of motor imagery, the focus of attention, and specific instructions vs. discovery learning. An example of an experiment in this category would be having one group receive typical motor learning training, and another group training using motor imagery, and have the groups switch conditions for the transfer test (Garbarini et al., 2018).

State Transfer: This category (n = 6, 4.44%) represents where the sensory or physiological state of the participant is manipulated. This category emphasizes the physical sensations of the participant during the experiment. This includes such manipulations as sleep deprivation, temperature, and arousal states. An example of this category is having one group learning a motor task under physically cold temperatures and the other group learning the motor task in a thermoneutral state. In the transfer test, groups switched to the opposite condition to assess motor skill performance (King et al., 2020). Another example of a state transfer study comes from Movahedi and colleagues (2007) where they manipulated levels of arousal in participants by having one group of physical education students under high arousal and the other group under low-arousal during a basketball free-throw task, and then groups would experience the other condition for the transfer test.

Virtual Environment Transfer: This category (n = 4, 2.96%) is when the task acquisition occurs in virtual reality and is transferred to a real environment. This category is a subset of the Ecological Validity Transfer category. By definition, Virtual Environment Transfer also transfers from a lab-based virtual task to a ‘real environment’ the same as Ecological Validity Transfer. Virtual Environment Transfer will serve as a subset, but separate category from Ecological Validity Transfer. Virtual Environment Transfer differs as it involves a quasi-reality component where the criterion context is different than the experiments in the Ecological Validity Transfer category. An example of an experiment in this category would be having groups with baseball batting practice in virtual reality or real batting practice and the transfer test assess performance in a real batting setting (Gray, 2017).

To demonstrate how the Virtual Environment Transfer category appears as a subset of Ecological Validity Transfer, a visual representation of this specification is included below (Figure 2.4). For the purposes of still separating these categories, and for visual interest of the ten taxonomies together, the former Figure 2.3 is recommended for conciseness.

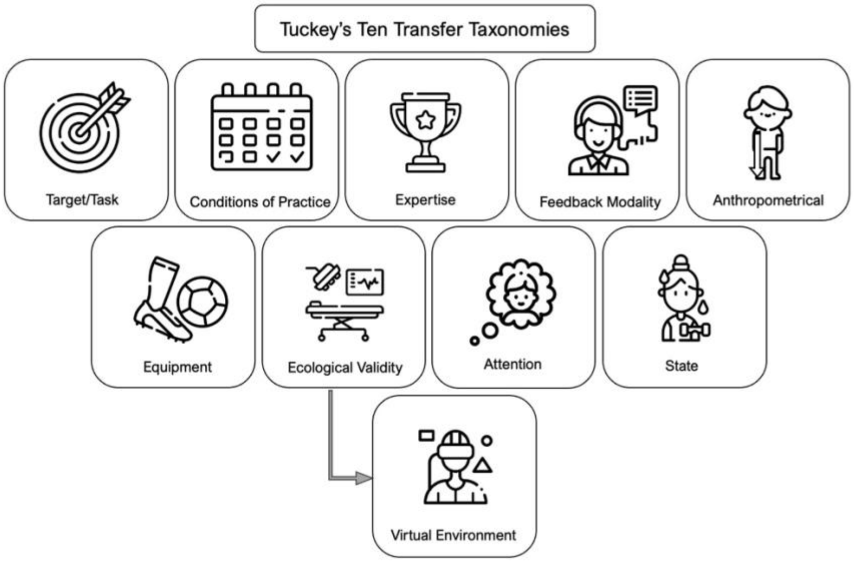


Figure 2.4: Tuckey's Ten Transfer Taxonomies including the visual representation of how Virtual Environment Transfer is a subset of Ecological Validity Transfer, but remains its own category.

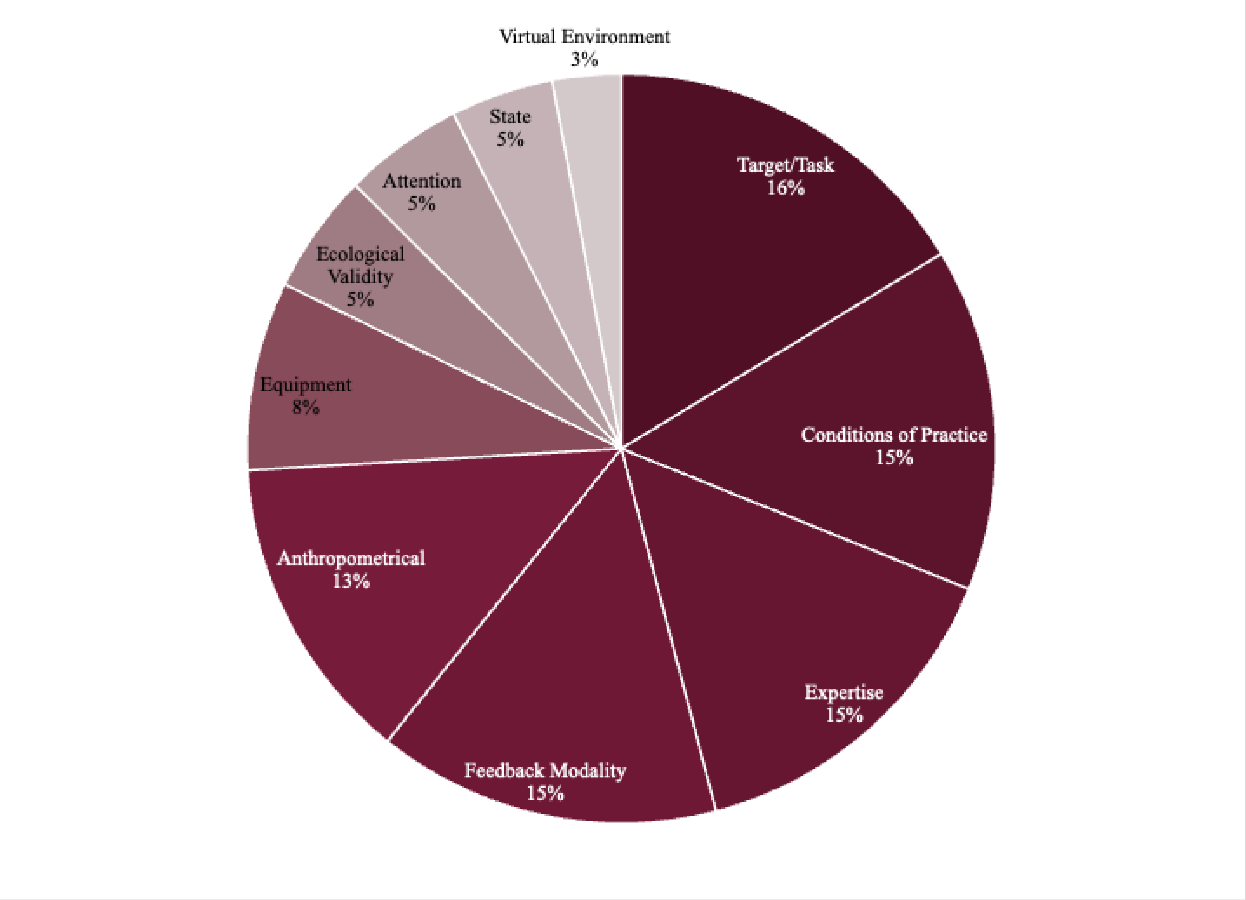


Figure 2.5: Number of articles (n = 135) represented as a percentage in each taxonomy

2.5.4 Objective 4: Any Commonalities

The results from the second and third research questions are combined to determine whether there are any major commonalities among the transfer test outcome (i.e., positive transfer, negative transfer, neutral transfer, or mixed results) and the taxonomy that the experiment was categorized into (i.e., ecological validity, anthropometrical, target/task, conditions of practice, state, expertise, feedback modality, virtual environment, attention, or equipment transfer). Each of the taxonomies outlines which experiments fall into their framework, and within the taxonomy, what the main outcomes of the transfer test were. The following results (Figure 2.6) are based on what the most common outcomes are for each category.

Figure 2.6: Pie charts to represent each taxonomy containing the proportion of studies that represent positive change (green, "+"), neutral transfer (yellow, "0"), negative change (red, "-"), and mixed results (purple, "x").

2.5.4.1 Target/Task (N = 22)

While occupying the most space in the literature on motor learning transfer test experiments, the Target/Task Transfer category leans primarily towards resulting in neutral transfer (N = 9). The experiments in the Target/Task Transfer category have a variety of motor tasks that range from fine motor star-tracing to gross motor slalom ski simulator task, with many other tasks in between (an arm level waveform task, a balance task, a stepping task, propelling a small disc over a tabletop task, a joystick moving a cursor task, a beanbag throwing task, and a four-finger force production task). None of these motor tasks really share a main commonality with the task as the body parts used are different, and some of the demographic populations are different. There are some commonalities in the target element of this category resulting in a neutral transfer that have accuracy components to the target goal that is being transferred (i.e., error percentage, root mean square error, the proportion of error, and radial error). Below are brief summaries of each of the experiments in the Target/Task Transfer category that result in a neutral transfer.

Bootsma and colleagues (2018) examined low, medium, and high task difficulty conditions and their effects on the learning of a star-tracing task measured by error percentage and movement time and found neutral transfer in transfer tests to untrained difficulty levels. Boutin and colleagues (2012b) examined early and late testing conditions on a horizontal arm lever waveform task measured by root mean square error and found neutral transfer on a transfer test to the original pattern. Giboin and colleagues (2019) examined participants learning three balance tasks, where results showed neutral transfer in transfer tests to novel balance tasks. Nourrit and colleagues (2000) examined participants with no ski simulator experience on learning a slalom ski simulator task measuring amplitude and frequency and found neutral transfer in a transfer test to novel amplitudes. Paul and colleagues (2018) examined participants with Parkinson’s disease on and off medication in a stepping task measuring response time and found neutral transfer in a transfer test to an untrained balance task. Sanli and Lee (2014) examined the learning of a task that involved the propelling a small disc over a tabletop measuring the proportion of error and radial error with experiment one transferring to a new target size, and experiment two transferring to a new target location, both resulting in neutral transfer. Stanley and Franks (1990) examined learning to use a joystick to move a cursor on an oscilloscope screen measured by amplitude and found neutral transfer in a transfer test to a new waveform. Willey and Liu (2018) examined specified compared to varied practice on a beanbag throwing task with neutral transfer found in a transfer test to longer and shorter target distances. Wu and colleagues (2015) examined a four-finger accuracy force production task measured by root mean square error and found neutral transfer in a transfer test to a grasping task.

2.5.4.2 Conditions of Practice (N = 20)

Another large occupying space of the motor learning transfer test literature is the Conditions of Practice Transfer studies. The studies in this taxonomy category have an assortment of results with the most common outcome being positive transfer (N = 9). This category has a variety of conditions of practice that are transferred positively (random order, precise condition, free condition, whole practice, increasing task difficulty conditions, short and long-term learning strategies, yoked knowledge of results, variable practice, discovery condition, and looped sequence condition). Such variety in these practice criterion conditions fails to extract a single reason why this taxonomy category is more likely to result in a positive transfer. Below are brief summaries of each of the experiments in the Conditions of Practice Transfer category that result in a positive transfer.

Albaret and Thon (1998) examined participants learning a motor task using a PowerBook and stylus pattern recreations of line segments and found positive transfer to modified figures in random order presentation. Bilodeau (1965) examined air force airmen performing a two-hand tracking four-leaf clover task with positive transfer observed in experiment one where all three target size groups (precise, moderate, free) transferred to a precise condition. Positive transfer was also found in experiment two where half of the participants transferred to moderate, and half transferred to the free condition. Chan and colleagues (2015) examined the effects of part practice compared to whole practice in children juggling novices and found a positive transfer to a reverse juggling task. Christiansen and colleagues (2018) examined a fixed compared to progressively increasing task difficulty conditions on a visuomotor tracking task on a pinch force transducer measured by the percentage of time on target and found positive transfer to a mirrored version. Correa and de Souza (2009) examined the motor learning of different strategies (i.e., generic vs. long-term difficult vs. long-term easy vs. short and long-term difficult vs. short and long-term easy) to climb the Bachman ladder and found positive transfer when starting the climb with the opposite foot in a transfer test. Figueiredo and colleagues (2018) examined self-controlled compared to yoked knowledge of results compared to yoked conditions in transporting a tennis ball in a specific sequence motor task and found positive transfer to a new target sequence. Kantak and colleagues (2011) examined constant practice compared to variable practice effects on the motor learning of a forearm lever task measured by root mean square error with positive transfer to movements outside the range of practice parameters. Singer and Pease (1976) examined guided compared to discovery compared to a combination of the two conditions' effects on the motor learning of a computer-managed novel serial manipulation task with positive transfer found when all groups switched to the discovery condition. Van Ooteghem and colleagues (2010) examined an embedded sequence compared to a looped-sequence condition of practice effect on a balance task requiring participants to stand on a hydraulically driven platform translated horizontally, forward, and backward found positive transfer when participants were given random perturbations in a transfer test.

2.5.4.3 Expertise (N = 20)

A large area of the motor learning transfer literature is also occupied by Expertise Transfer. Expertise Transfer is the only category to have revealed negative transfer (N = 8) as the most likely outcome. To reiterate, Expertise Transfer is the only category where motor task acquisition and retention occur outside of the experiment. Essentially, the participants in the Expertise Transfer category are coming into the experiment with previous experience on a motor task, and the experiment is only testing for the transfer of the previous experience. All of the studies in the Expertise Transfer that result in negative transfer relate to having sports experience (senior basketball players, elite basketball players, handball goalkeepers, wrestlers, college physical education students, college baseball pitchers, and experienced basketball players). Below are brief summaries of each of the experiments in the Expertise Transfer category that result in a negative transfer.

Czyz and colleagues (2013) examined male basketball players grouped by senior players, a cadet group, and a junior group and found a negative transfer to shot distances other than the free throw line from the previous senior experience. Fay and colleagues (2013) examined elite male basketball players with the task of a basketball shot from five distances and found negative transfer from the previous experience at distances that are not the free throw line. Helm and colleagues (2016) examined handball goalkeepers compared to novices in domain-unspecific simple or choice stimulus-response tasks as well as domain-specific choice stimulus-response tasks and found negative transfer for the goalkeeper's previous experience. Moufti and Arfaoui (2019) examined males with seven years of wrestling experience compared to practice wrestlers but with judo experience on an attack to the opponents' legs measured by angle and speed and found a negative transfer from the previous expertise. Nelson (1957) examined men in college physical education classes in paired sport training conditions and found negative transfer to other sports (badminton, tennis, volleyball, basketball, track, and football). O'Keeffe and colleagues (2007) examined the fundamental overarm throw compared to badminton overhand clear compared to a control condition with no practice and found negative transfer to a badminton clear and a javelin throw. Simons and colleagues (2009) examined college baseball pitchers at various pitching distances measured by accuracy and percentage strike and found a negative transfer from previous pitching distance experience. Stoeckel and Breslin (2013) examined experienced basketball players in a regular court setting, in a further free throw setting, and in a closer free throw setting and found negative transfer to the other distances.

2.5.4.4 Feedback Modality (N = 20)

The Feedback Modality Transfer category contains the most polarizing results of the motor learning transfer literature. The majority of the studies in this category have a positive transfer (N = 8), but the second largest pie chart slice in this category represents a negative transfer (N = 5). Between the studies in the Feedback Modality Transfer category that result in positive transfer, there was not one main type of feedback that demonstrates positive transfer, the results are scattered (verbal instructions, eyes covered, guidance condition, rotated feedback display, video knowledge of performance, magnified conditions, amount of delayed feedback, gaze training, movement training, and discovery learning). Below are brief summaries of each of the experiments in the Feedback Modality Transfer category that result in a positive transfer.

Buchanan and Dean (2010) examined college students with either a verbal instruction group or a discovery group in a circle tracing with a stylus task and found positive transfer when switching to untrained patterns. Elion and colleagues (2008) examined the effects of training one group of participants in a virtual environment while maintaining balance on a moving platform compared to no training and found a positive transfer to a synchronized visual input condition with eyes covered. Heinen and colleagues (2010) examined female gymnasts in guidance compared to a no-guidance control condition in a somersault beam dismount and beam cartwheel task and found positive transfer later when all participants performed under the condition of no guidance. Langan and Seidler (2011) examined young compared to older adults in a joystick adaptation task measured by reaction time and errors and found positive transfer on a rotated feedback display transfer task. Nunes and colleagues (2020) examined the effects of verbal knowledge of performance compared to video knowledge of performance compared to both on a golf putting task measured by absolute error and variable error and found positive transfer when putting to a different direction and distance. Roller and colleagues (2009) examined lens-training sham compared to magnifying compared to reducing compared to views upwards and downwards on an object avoidance walking task and found positive transfer to the same walking task under the condition of a right-shift lens. Vickers and colleagues (1999) examined novice, intermediate, and advanced undergraduate baseball hitters under conditions of simple to complex instruction, variable practice, and lots of feedback compared to decision training with complex instruction, variable practice, and reduced delayed feedback on a baseball hitting task at 94km/hr in a batting cage scored by the percentage of hits found positive transfer when ball speed was faster and slower. Wilson and colleagues (2011) examined medical trainees with no laparoscopic experience under the condition of gaze training, movement training, and discovery learning on an eye-hand coordination task on a VR laparoscopic surgical simulator and found positive transfer to a dual-task distraction tone counting.

2.5.4.5 Anthropometrical (N = 18)

The Anthropometrical Transfer category results in an equal split between positive transfer (N = 6) and neutral transfer (N = 6) studies. The body parts involved in the anthropometric transfer seem to be similar in both the positive transfer outcomes (unimanual to bimanual, right side to the left side, untrained leg, whole arm movement, opposite hand) and the neutral transfer outcomes (opposite arm, opposite hand, heel movements to whole gait patterns, and unimanual to bimanual). Below are brief summaries of each of the studies in the Anthropometrical Transfer category that result in a positive transfer and a neutral transfer.

A result of positive transfer in an anthropometrical experiment is by Avila-Mireles and colleagues (2017) using a unimanual and dyadic haptic manipulandum with force fields in a time-to-target task and transferred to an individual bimanual version of the task. James (2012) examined the motor learning of the right side of the body's range of motion positions (sitting on the floor feet left or feet right twisting position marked in degrees) transferred to testing the left side of the body and found positive transfer. Krishnan and colleagues (2018) examined a new gait pattern measured with foot trajectories where positive transfer was found on the untrained leg. Orrell and colleagues (2007) examined right hemisphere stroke patients in a serial reaction time task and found positive transfer to whole arm movement on a larger scale board task. Pereira and colleagues (2011) examined practical dexterity tasks like picking up rice and putting it in a container and screwing and unscrewing nuts and bolts to find a positive transfer in the other hand. Rajan and colleagues (2019) used an isometric force production task in conditions of arm training, hand training, and no training on a robotic exoskeleton to control an on-screen cursor measured by time duration and success rate with a positive transfer seen when participants switched to the other hand or arm conditions.

Neva and colleagues (2019) used a rest and an exercise group in a visuomotor rotation task in the right arm where peak lateral displacement and movement time was examined, finding neutral transfer when transferred to the other arm. Romkema and colleagues (2015) examined the influence of short and long-interval training compared to short and long-interval control groups in a functional grip task and a grip force control task and they found neutral transfer in performance in a transfer test on the other hand.

Seitz and Wilson (1987) examined the learning of heel up and heel down, short, and long rhythm tasks effects on the gait pattern and found neutral transfer in this transfer test. Teixeira and Caminha (2003) examined symmetric force, asymmetric force, and control conditions effects on launching a small cart across a track with the preferred hand, transfer test results on the other hand revealed neutral transfer in performance. Van der Kooij and colleagues (2016) examined predicted, vision and proprioception conditions using a pointing task with a transfer test to the other hand finding neutral transfer in performance. Yokoi and colleagues (2017) examined unimanual sequence A&B, unimanual sequence C&D, bimanual A1&B2, and bimanual learning of a discrete sequence production task with fingers, finding neutral transfer in performance when participants switched to the other sequences in a transfer test.

2.5.4.6 Equipment (N = 11)

The Equipment Transfer category's main results are an equal split between positive transfer (N = 4) and neutral transfer (N = 4) studies. The types of equipment, or how the equipment changes do not share any commonalities within the positive transfer (a new putter, soccer ball to a futsal ball, different colonoscopy training surfaces, a soccer ball to a foam rubber ball) or the neutral transfer (tilt board to slackline, mouse to button press, small to big ball, barefoot to shoed). To follow are brief summaries of each of the studies in the Equipment Transfer category that result in a positive transfer and a neutral transfer.

Bested and colleagues (2019) examined no guidance compared to 50% guidance conditions on a golf putting task with vision occluded after the hit and participants press on a screen when they think the ball landed task measured by absolute error estimation found positive transfer when performing the second target with a new putter. Oppici and colleagues (2018) examined adult novices under the conditions of using a futsal ball compared to a soccer ball in a pass a moving ball with foot task measured by performance accuracy and found positive transfer when both conditions were given the futsal ball to perform with. Riek and colleagues (2017) examined experienced colonoscopists compared to novices in using a colonoscope to track 28 targets measured by completion time and found positive transfer when groups switched to different training surfaces. Vera and colleagues (2008) examined nine-year-old children under the conditions of blocked, variable, and a combination in a soccer ball dribbling and kicking task and found positive transfer when the children switched to a foam rubber ball.

Giboin and colleagues (2018) in experiments one and two examined students under the conditions of a tilt board, a tilt board and slack line, and control in tilt board balance tasks and found neutral transfer when groups switched to the other balance training. Grzeczkowski and colleagues (2017) examined participants either in a mouse or a button press group in an adjusting the central line of vertical bisection task measured by mean offset and found neutral transfer when participants switched to the other group. Raastad and colleagues (2016) examined adolescent soccer players with a small ball compared to a big ball group in a soccer ball juggling task and found neutral transfer when participants switched back to a regular ball. Zech and colleagues (2018) examined healthy adults in barefoot, shod, and a control condition in a stability platform task measured balance in seconds and found neutral transfer as participants switched to the other conditions.

2.5.4.7 Ecological Validity (N = 7)

From the motor learning transfer test literature, the studies that fit into the Ecological Validity Transfer category primarily result in having positive transfer (N = 4). There is a lack of a primary commonality between the types of tasks in this category that result in having a positive transfer (peg transfer task to a surgical simulation-based task, spooning stones to cornflakes, Wii Fit training to a function reach test, a laparoscopic cutting task on gauze to abdominal tissue cutting). To follow are succinct summaries of each of the studies in the Ecological Validity Transfer category that result in a positive transfer.

Abdelrahman and colleagues (2018) examined a peg transfer task and found positive transfer when transferring to a surgical simulation-based task. Jo and colleagues (2020) examined a stroke patient population practicing spooning stones and transferring to spooning cornflakes, resulting in positive transfer. Mendes and colleagues (2012) examined Wii Fit training and found a positive transfer to function reach testing in Parkinson’s disease patients. Nemani and colleagues (2019) examined a laparoscopic cutting task on gauze as practice and found positive transfer to abdominal tissue cutting.

2.5.4.8 Attention (N = 7)

From the motor learning transfer test literature, the studies that fit into the Attention Transfer category primarily result in having positive transfer (N = 5). There are no fundamental similarities between the types of studies within the Attention Transfer studies that result in having a positive transfer (internal or external focus of attention, engaging or sterile games, mental pre-performance routines or self-regulated or no routine, physical or mental practice, discovery learning or gaze training). Next are brief summaries of each of the studies in the Attention Transfer category that result in having a positive transfer.

Kakar and colleagues (2013) examined patients with Parkinson’s disease under the conditions of internal focus or external focus of attention in a dart throwing to a target task and found positive transfer when the target distance for both groups increased by one meter. Lohse and colleagues (2016) examined participants in an engaging game group compared to a less engaging sterile group in a Microsoft Kinect computer game task measured by points per block and found positive transfer when groups switched to the opposite condition. Moradi (2020) examined undergraduate male students under the conditions of a five-step mental pre-performance routine compared to a self-regulated mental pre-performance routine compared to a no pre-performance routine on a basketball free-throw task measured by the sum of points found positive transfer when presented with a new shooting angle. Sharif and colleagues (2015) examined males with cerebral palsy under the conditions of physical practice, mental practice, and a control condition in a dart-throwing task and found positive transfer when all participants switched to dart-throwing from a further distance. Vine and colleagues (2013) examined medical students in a discovery learning compared to a gaze training condition in picking and dropping balls task measured by completion time and target locking score and found positive transfer when participants switched to the task being two-handed.

2.5.4.9 State (N = 6)

In the motor learning transfer test literature, the State Transfer studies show no results for positive transfer. The primary outcome of State Transfer studies in the motor learning transfer test literature is neutral transfer (N = 4). Of the four studies in State Transfer with the most common result (neutral transfer), there is no consistency between the types of states that are being manipulated (fatigue levels, pain levels, time of day, and participants with Parkinson's disease on or off of medication). Next are brief summaries of each of the studies in the State Transfer category that result in a positive transfer.

Barnett and colleagues (1973) examined fatigued compared to non-fatigued female students in moving an arm in a sigma-like motion measured by time and found neutral transfer in a transfer test to the opposite as their trained condition. Bouffard and colleagues (2016) examined pain compared to control conditions on a treadmill walking adaptation task to an ankle perturbation task measured by electromyography and found neutral transfer when participants switched to walking without pain. Genzel and colleagues (2012) examined the effects of one group arriving in the morning compared to the other group arriving in the evening on the motor task of DanceStage choreography with arrows as a PlayStation video game and found neutral transfer as participants transfer to a new song. Paul and colleagues (2020) examined participants with mild-moderate Parkinson's disease either training on or off of medication in the motor learning of a non-dominant functional motor task kidney bean scooping into cups task found neutral transfer as participants switch to performing a peg transfer task and functional task on medication.

2.5.4.10 Virtual Environment (N = 4)

The smallest category of the motor learning transfer test literature is Virtual Environment Transfer. Virtual Environment Transfer studies in the motor learning transfer test literature tend to result in positive transfer (N = 2). The two tasks in the Virtual Environment Transfer category that result in positive transfer are quite different from one another (virtual reality vs. real baseball batting, and virtual vs. reality (on a simulator) surgery task). Next is a summary of the studies in the Virtual Environment Transfer category that result in a positive transfer.

Gray (2017) examined adaptive hitting training in virtual reality compared to extra sessions of batting practice in virtual reality compared to extra sessions of real batting compared to a no training control on a baseball batting task measured by the mean number of hits and found positive transfer when the conditions switched to real batting. Yang and colleagues (2018) examined surgical novices in virtual reality compared to a reality condition on an appendectomy training task measured by total movements and found positive transfer when both groups performed a cholecystectomy on the simulator.

Table 2.2: Combination of transfer test outcome (positive transfer, neutral transfer, negative transfer and mixed results) with the number of studies in each taxonomy category

	Ecological validity (n=7)	Anthropometrical (n=18)	Target/Task (n=21)	Equipment (n=11)	State (n=6)	Expertise (n=20)	Feedback Modality (n=20)	Conditions of Practice (n=20)	Virtual Environment (n=4)	Attention (n=7)
Positive transfer	4	6	5	4	0	6	8	9	2	5
Neutral transfer	1	6	9	4	4	1	3	4	1	1
Negative transfer	0	1	1	1	1	8	5	1	0	1
Mixed results	2	5	6	2	1	5	4	6	1	0

2.6 Discussion

2.6.1 Objective 1: Survey of Generalizability and Specificity

The purpose of this scoping review is to explore the range of articles in the motor learning literature that includes learning a motor task and analyzing the outcome of their transfer test. This scoping review started with an initial 1266 studies and was filtered down to a final 135 studies included. The number of studies included reflects the wide range of evidence on this topic, compared to previous reviews which had a narrower focus and a small number of included samples, such as Oppici and Panchuk (2022) with a primary focus on transfer in sports only included 17 studies. This review increases the scope of evidence in a synthesis approach of all the motor learning studies meeting strict predetermined inclusion criteria with some evidence of generalizability and/or specificity. The results of this survey of motor learning studies with generalizability and/or specificity demonstrate a more chaotic body of literature than motor learning researchers may be aware of.

2.6.2 Objective 2: Categorization into Positive Transfer/ Negative Transfer/ Neutral transfer/ Mixed Results

Based on the outcomes of the transfer test, results were categorized into positive transfer, neutral transfer, negative transfer, or mixed results. From the 135 articles analyzed, 49 (36.3%) demonstrated positive transfer, 34 (25.2%) demonstrated neutral transfer, 19 (14.1%) demonstrated negative transfer, and 33 (24.4%) demonstrated mixed results. This review demonstrates that in a motor learning setting that attempts to generalize the motor skill, the most common outcome is to have success to some degree of experiencing an element of motor skill generalizability. This indicates that the initial motor task that was learned was beneficial to performing the secondary motor task. Having over a third of studies in the positive transfer category is in line with the support available for the transfer-appropriate processing perspective, and the many benefits of motor task generalizability.

Approximately one-quarter of the initial motor tasks did not reveal any impact on the performance of a secondary motor task. A transfer test outcome with neutral transfer in motor performance is refreshing to see in the published literature and may be a deflated quantity based on publication biases of publishers and authors desiring to publish significant results. This category is important to see its prevalence as it can lead to more information about which motor tasks are unrelated to one another's transfer of learning.

Only 14.1% of studies resulted in some degree of negative transfer. This is demonstrated as the least likely outcome after having learned a motor task and attempting to apply that skill set to a secondary motor task. These results support the specificity of practice hypothesis, where the context under which the motor skill is practiced is so specific to that sensorimotor representation, that any deviation from that representation is costly to the learner (Proteau et al., 1992). The paucity of true negative transfer findings may be explained by the lack of advantages of creating a negative transfer situation for learners. Nonetheless, this information can be helpful for coaches, practitioners, teachers, and individuals in having a better understanding of which motor skills are more likely to cause a decrement in motor performance on those transfer skills.

2.6.3 Objective 3: Tuckey's Ten Transfer Taxonomy

A tertiary purpose of this review is to develop a taxonomy to guide the language used in the design of future studies related to transfer tests. Adams (1987) and Schwartz and colleagues (2005) describe how a wide variety of tasks and inconsistent findings in the transfer literature makes it difficult to draw conclusions or generalizations. Tuckey's Ten Transfer Taxonomy offers an organization of the types of transfer to aid in the descriptions surrounding the transfer test. Revealing a need for ten taxonomies demonstrates such variety that is currently existing in the motor learning literature. This taxonomy is now able to highlight the primary aspect of the motor skill that is being transferred, which was previously lacking in motor learning literature. The taxonomy remains broad and multidisciplinary to include any motor task across any population. The broadness of this taxonomy is both a strength and a limitation to this chapter. The broadness of the taxonomy poses as a strength where it can include multidisciplinary research (e.g., special populations, athletes, activities of daily living, etc.). This can help to bridge the gap between disciplines researching similar transfer concepts but under different contexts. The broadness of the taxonomy also poses a weakness where there is such variety in the results, leading to inconclusive results. Perhaps future research can add additional subcategories to narrow the focus of the taxonomy to further investigate commonalities within specificity and generalizability results.

2.6.4 Objective 4: Any Commonalities

The fourth purpose of this review is to determine if any commonalities exist between the transfer test outcome and the taxonomy that the study has been categorized into. This review containing all studies that tested for the amount of motor skill generalizability or specificity is important because the literature is filled with motor learning studies with various outcomes that have yet to be compiled and assessed for commonalities. Here, the outcomes of the positive transfer, neutral transfer, negative transfer, mixed results, and the usage of Tuckey's Ten Transfer Taxonomies are discussed. With such variety and overlap between which taxonomies represent each type of transfer, this makes generalizing the findings of this review difficult. There is neither one taxonomy that only represents studies that result in generalizability, nor one taxonomy that only produces a specificity of motor learning outcome. Though the results section outlined each taxonomy category with which was the primary outcome for each category, this does not mean that was the only outcome in that category. For brevity, only the top outcomes were summarized, however, summaries of all category outcomes can also be found in the appendices.

The results of this review reveal much overlap, with several of the taxonomies populating each of the transfer outcomes. Conflicting theories of both transfer-appropriate processing and specificity of practice are co-existing in similar spaces of motor learning as seen through the taxonomy categories. To pinpoint a type of transfer from the taxonomy to suggest that humans will always experience a decrement or will always receive a benefit when switching motor tasks has been revealed to be unrealistic.

2.7 Conclusions

Chapter one of this thesis focuses on defining motor learning, classifying movements, actions, and skills, the performance-learning distinction, requirements of motor learning, neural correlates of motor learning, theoretical perspectives of motor learning, conditions of practice, and the generalizability and/or specificity of motor practice. Chapter two of this thesis is a scoping review to map existing literature on transferring motor task skills from a previously acquired task to a new task or skill. More specifically, the scoping review addresses the following research objectives:

1) Surveys systematically peer-reviewed literature that reports experimental results involving learning a motor task with transfer test measures.

2) Categorizes the transfer results to support or refute notions of specificity or generalizability of learning a motor task, evaluated as positive transfer, negative transfer, no change, or mixed results.

3) Develops a taxonomy that offers a common framework for exploring and contextualizing the relative specificity or generalizability of motor skills by providing a structure to develop and utilize more consistent language and terminology, use transfer testing protocols that are appropriate for the context and goals of their experiments, and for cross-comparing research studies that employ different motor skill transfer protocols.

4) Determines if there exists any commonality between the taxonomy and transfer test outcome that points toward motor training protocols that are more likely than not to lead to generalizability or specificity of practice.

Based on the information gained from these chapters, certain limitations in the motor learning literature, with respect to how existent studies assessing motor skill acquisition, retention and transfer, were identified and will now be addressed. As noted throughout

Chapters one and two, these limitations primarily centre on the fact that consistency among these studies concerning definition of terms, types of tasks/protocols used and, interpretations of data obtained, is generally lacking. In this chapter, we revisit these issues and create what we hope to be a "template" for future studies of this type, by creating a cohesive "best practices" checklist for future researchers conducting transfer test protocols. This chapter also serves as a bridge to connect the chapter two scoping review and chapter four protocol design.

2.7.1 Limitations in the motor learning literature

The main limitations that this scoping review is uncovering in the motor learning literature highlight: not having a retention test of sufficient duration; the actual intention of that transfer test, and too many independent and/or dependent variables for the motor task being used. These limitations led to disappointment in the data collection process of this scoping review, making the gathering of definitive results from each study tumultuous. Details into the main limitations found are outlined below.

2.7.1.1 Duration of Retention Interval

The purpose of having a retention test is to assess the relative permanence that the learner has acquired because of practice on a motor task (Adams, 1964; Fitts, 1964; Newell, 1991). To assess the relative permanence, this suggests that the retention test should be after a duration of time during which no further practice occurs (see Chapter 1, Requirements of Motor Learning). This is not to discourage the implementation of an immediate retention test as well, but an immediate retention test should not be the only measure of retention. An immediate retention test can be used to isolate the change of one variable, typically the withdrawal of extrinsic feedback from acquisition to assess how well a participant's performance is on their own, in the absence of extrinsic feedback. Then, the implementation of a delayed retention test in addition to an immediate retention test, can also only change one variable, keeping the exact same format as the immediate retention test, only it is at least 24 hours later, on a different day. Now, the researcher can compare performance on the motor task at the beginning of acquisition to the immediate retention test and then can compare the two retention tests to each other rather than passing over some important information if the acquisition is strictly compared to the delayed retention test. If the sole retention test is less than 24 hours, this implies that the experiment is not a motor learning study, as there is no real reliable evidence of relative permanence of the motor skill. As discussed by Christina (1997), the sole use of an immediate retention test will be contaminated with temporary effects from acquisition (e.g., massed practice) and may not appropriately reflect learning. Best practices of retention tests should use an immediate retention test and a delayed retention test, both tested under the same experimental conditions (Christina, 1997).

2.7.1.2 Format of Transfer Test Protocol

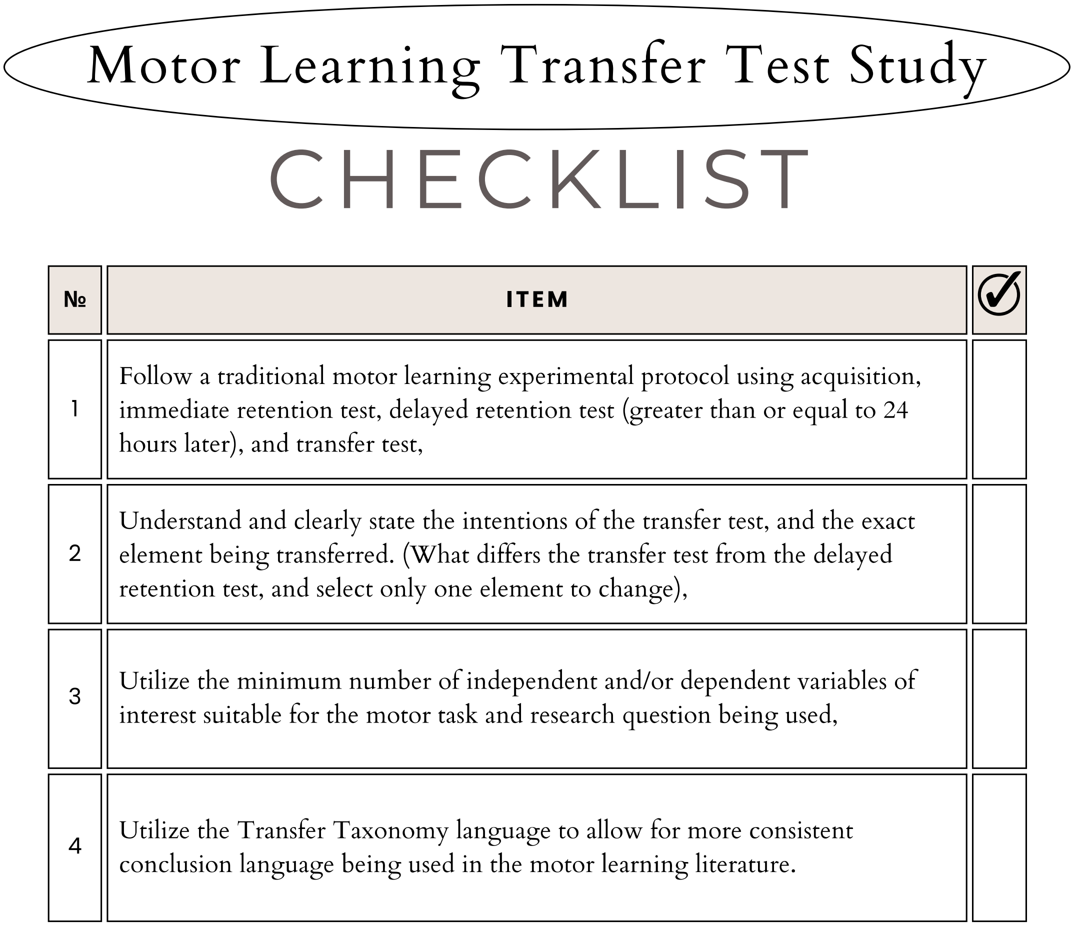
Another limitation found from the scoping review results in chapter two is the wide variety of transfer tests being used in motor learning experiments. Without clear intention and direction in a transfer test, results can be uninformative and vague. Researchers should have a clear plan as to adapting only one element from the retention test into the transfer test. All too often, researchers tweak more than one element in the transfer test and are left with a contaminated transfer test. For example, if the experiment is a condition-of-practice experiment where one group practiced a motor task under the condition of blocked practice, and the other group practiced under the condition of random practice, a retention test would occur 24 hours later and without feedback, and a transfer test could be to have the groups switch conditions that they perform under. This would isolate the transfer element where the blocked group is now transferring to performing under a random condition. Too often, researchers do not consider a condition of practice as a factor that can be transferred, and researchers will add a new task transfer as well such as changing the soccer ball in the motor task to a futsal ball. In this instance, there would now be two elements that are being transferred for the first time, which does not isolate a transfer task.

2.7.1.3 Development of Independent and Dependent Variables

Another point of contention in the motor learning literature that was evident in this scoping review was the lack of clean and straightforward use of independent and dependent variables. It appears that simple designs for studying motor learning have become a lost art. Having a “simple” motor learning study design starts with using a motor task that is best suited to answer the research question. The motor task needs to be sensitive to the research question and utilize the applicable motor systems that are hypothesized to be affected by the intervention. Depending on the research question, either a discrete, serial, or continuous motor task may be appropriate. From here, it is important to utilize only the dependent measures of interest that will be appropriate for the motor task. While there are always additional questions that can be asked alongside the main research question, these additional measures can cloud the main outcomes of the study.

2.7.2 Checklist for transfer test studies

We recommend that future researchers conducting motor learning experiments designed to assess the specificity of practice should use the below list of recommended protocol practices to be followed (Figure 2.7). This can ensure the goal that the researcher can isolate the research question and be able to come to more definitive conclusions as to whether or not a specificity of practice exists under the chosen intervention.



Motor Learning Transfer Test Study

CHECKLIST

№	ITEM	✓
1	Follow a traditional motor learning experimental protocol using acquisition, immediate retention test, delayed retention test (greater than or equal to 24 hours later), and transfer test,	
2	Understand and clearly state the intentions of the transfer test, and the exact element being transferred. (What differs the transfer test from the delayed retention test, and select only one element to change),	
3	Utilize the minimum number of independent and/or dependent variables of interest suitable for the motor task and research question being used,	
4	Utilize the Transfer Taxonomy language to allow for more consistent conclusion language being used in the motor learning literature.	

Figure 2.7: Motor Learning Transfer Test Study Checklist

2.8 Funding

This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) agency through a discovery grant award.

2.9 Appendix A: Reporting Items for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	62
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	62-63
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	68
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	68-69
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	69
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	70-71
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	72
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	113
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	71-72
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated	71-72

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
		forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	71-72
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	N/A
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	71-72
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	72-73
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	12-44
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	74-106
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	83-106
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	107-108
Limitations	20	Discuss the limitations of the scoping review process.	107-108
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and	107-108

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
		objectives, as well as potential implications and/or next steps.	
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	109

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

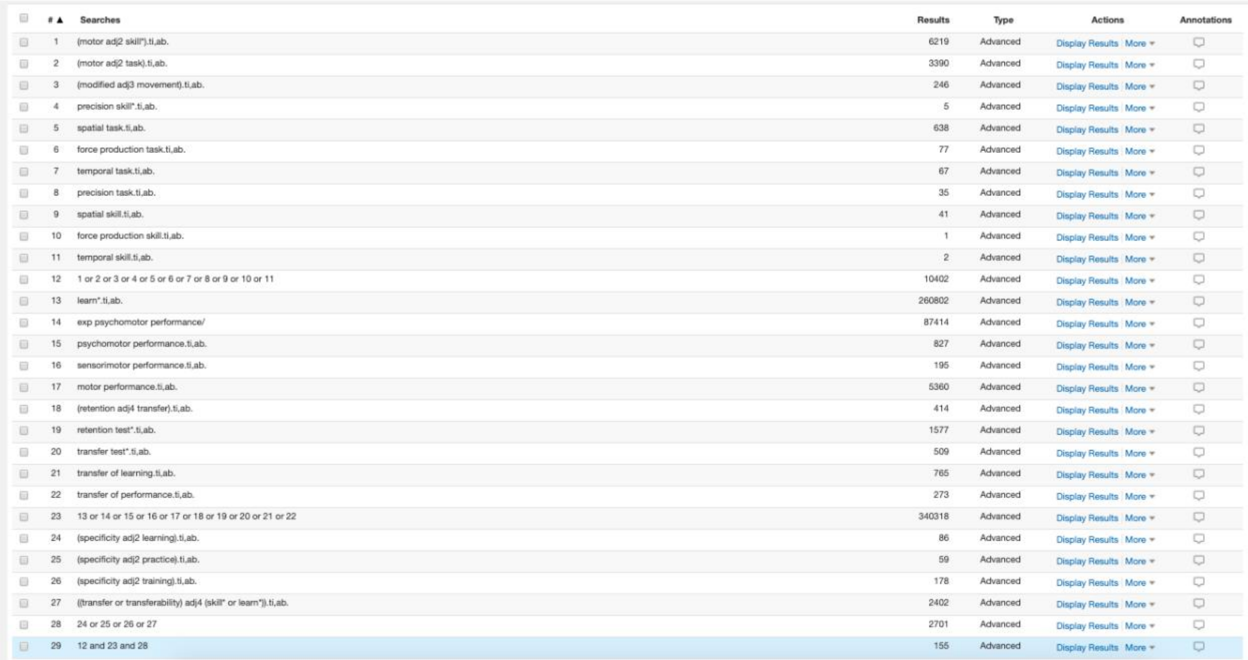
† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O’Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018; 169:467–473.

2.10 Appendix B: Full Title and Abstract Search Strategy for Medline as an Example Database (03/20/2020)



☐	# ▲	Searches	Results	Type	Actions	Annotations
☐	1	(motor adj2 skill*).ti,ab.	6219	Advanced	Display Results | More ▾	
☐	2	(motor adj2 task).ti,ab.	3390	Advanced	Display Results | More ▾	
☐	3	(modified adj3 movement).ti,ab.	246	Advanced	Display Results | More ▾	
☐	4	precision skill*.ti,ab.	5	Advanced	Display Results | More ▾	
☐	5	spatial task.ti,ab.	638	Advanced	Display Results | More ▾	
☐	6	force production task.ti,ab.	77	Advanced	Display Results | More ▾	
☐	7	temporal task.ti,ab.	67	Advanced	Display Results | More ▾	
☐	8	precision task.ti,ab.	35	Advanced	Display Results | More ▾	
☐	9	spatial skill.ti,ab.	41	Advanced	Display Results | More ▾	
☐	10	force production skill.ti,ab.	1	Advanced	Display Results | More ▾	
☐	11	temporal skill.ti,ab.	2	Advanced	Display Results | More ▾	
☐	12	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11	10402	Advanced	Display Results | More ▾	
☐	13	learn*.ti,ab.	260802	Advanced	Display Results | More ▾	
☐	14	exp psychomotor performance/	87414	Advanced	Display Results | More ▾	
☐	15	psychomotor performance.ti,ab.	827	Advanced	Display Results | More ▾	
☐	16	sensorimotor performance.ti,ab.	195	Advanced	Display Results | More ▾	
☐	17	motor performance.ti,ab.	5360	Advanced	Display Results | More ▾	
☐	18	(retention adj4 transfer).ti,ab.	414	Advanced	Display Results | More ▾	
☐	19	retention test*.ti,ab.	1577	Advanced	Display Results | More ▾	
☐	20	transfer test*.ti,ab.	509	Advanced	Display Results | More ▾	
☐	21	transfer of learning.ti,ab.	765	Advanced	Display Results | More ▾	
☐	22	transfer of performance.ti,ab.	273	Advanced	Display Results | More ▾	
☐	23	13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22	340318	Advanced	Display Results | More ▾	
☐	24	(specificity adj2 learning).ti,ab.	86	Advanced	Display Results | More ▾	
☐	25	(specificity adj2 practice).ti,ab.	59	Advanced	Display Results | More ▾	
☐	26	(specificity adj2 training).ti,ab.	178	Advanced	Display Results | More ▾	
☐	27	((transfer or transferability) adj4 (skill* or learn*)).ti,ab.	2402	Advanced	Display Results | More ▾	
☐	28	24 or 25 or 26 or 27	2701	Advanced	Display Results | More ▾	
☐	29	12 and 23 and 28	155	Advanced	Display Results | More ▾	

2.11 Appendix C: Positive Transfer

Specificity*	Year	Author	Title	Participants (Groups)	Demographics**	Motor task (measures)	Transfer duration (task)	Type of Transfer***
1	2018	Abdelrahman et al.	Validation of a novel inverted peg transfer task: Advancing beyond the regular peg transfer task for surgical simulation-based assessment	36 novices (1st year residents/medical students) vs. 8 experts (attending surgeons >3 years)	4	Peg transfer (completion time, # of drops, # of transferred triangles)	Same day (from previous expertise)	EV
1	1998	Albaret & Thon	Differential effects of task complexity on contextual interference in a drawing task	144 undergraduates (Blocked + 2 segments vs. Blocked + 3 segments vs. Blocked + 4 segments vs. Random + 2 segments vs. Random + 3 segments vs. Random + 4 segments)	0	PowerBook and stylus pattern recreations of line segments (Absolute distance error, directional error,	Immediate, 24 hours (modified figures in random order)	CP

						bidimensional variable error)		
1	2017	Avila-Mireles et al.	Skill learning and skill transfer mediated by cooperative haptic interaction	30 volunteers (14 naive females vs. 14 naive males vs. 1 expert female vs. 1 expert male) (Train with peer vs. train with expert)	4	bimanual manipulandum (time to target)	5 days (Transfer to bimanual)	AN
1	2019	Bested et al.	The influence of robotic guidance on error detection and correction mechanisms	34 participants (no guidance, 50% guidance)	0	golf putting task vision occluded after hit, press on screen where you think the ball landed (absolute error estimation)	24 hours (second target new putter)	EQ
1	2005	Bebko et al.	Transfer, control, and automatic processing in a complex motor task: an	9 psychology graduate students (4 with juggling experience vs. 5 with no experience)	4	Juggling (Average number of catches)	From previous juggling experience	EX

			examination of bounce juggling					
1	1965	Bilodeau	Transfer of training across target sizes	48 airmen from airforce (Ex. 1) 66 participants (Ex. 2) (Precise vs. Moderate vs. Free)	4	Two-Hand tracking four leaf clover (Mean number of circuits of the path)	24 hours (Ex. 1) everyone transfer to Precise condition (Ex. 2) Transfer half transferred to Moderate, half transferred to Free)	CP
1	2010	Buchanan & Dean	Specificity in practice benefits learning in novice models and variability in demonstration benefits observational practice	32 college students (verbal instruction group vs. discovery group)	0	Trace circle with stylus (phase)	24 hours (symmetric and asymmetric pattern and trained pattern)	FB
1	2015	Chan et al.	Children's age modulates the effect of part and whole practice in motor learning	106 children in grades 1, 3, 5 juggling novices (Part Practice vs. Whole Practice)	3	3 bean bag juggling (# of catches before dropping)	8 days (reverse juggling)	CP

1	2018	Christiansen et al.	Progressive practice promotes motor learning and repeated transient increases in corticospinal excitability across multiple days	24 male participants (Fixed or Progressively increasing task difficulty)	0	Visuomotor tracking task on a pinch force transducer (Time on Target %)	8 days (mirrored version)	CP
1	2009	Correa & de Souza	Effects of goal difficulty and temporality in motor skill acquisition using the Bachman ladder	100 participants (Generic vs. long-term difficult vs. long-term easy vs. short and long-term difficult vs. short and long-term easy)	0	Bachman ladder (number of rungs climbed before losing balance)	5 minutes (Start climb with opposite foot)	CP
1	2016	Czyz et al.	Specificity vs. generalizability: Emergence of especial skills in classical archery	(Ex. 1) 10 male experienced archers (Ex. 2) 8 female archers	4	Archery shots from different distances (Score in points)	From previous archery experience	EX
1	2008	Elion et al.	Postural adjustments as	7 healthy men (trained vs. control)	0	virtual environment	24 hours, 4 weeks, 12 weeks	FB

			an acquired motor skill: Delayed gains and robust retention after a single training session within a virtual environment			maintaining balance on a moving platform (CoP displacement, MT)	(synchronized visual input, eyes covered)	
1	2018	Figueiredo et al.	External control of knowledge of results: Learner involvement enhances motor skill transfer	30 undergraduate students (self-controlled vs. KR yoked vs. involvement yoked)	0	transport tennis ball in a specific sequence (AE, CE, VE, Spatial error)	24 hours (new target sequence)	CP
1	2017	Gray	Transfer of training from virtual to real baseball batting	80 participants (adaptive hitting training VR vs. extra sessions of batting practice in VR vs. extra sessions of real batting vs. control no training)	0	baseball batting (mean number of hits)	1 month (real batting)	VE
1	2010	Heinen et al.	When is manual guidance effective for the acquisition of	52 female gymnasts (guidance vs. control no guidance groups)	4	somersault beam dismount and beam	1 week (no guidance)	FB

			complex skills in Gymnastics?			cartwheel (performance rating 10-point scale)		
1	2012	James	Body movement instructions facilitate synergy level motor learning, retention and transfer	24 young adults (body movement or movement outcome instruction groups)	0	sit on carpeted floor in two different positions with laser on hat, turn to see as far as you can (range of motion)	24 hours (left side of body)	AN
1	2020	Jo et al.	Effects of contextual interference on feeding training in patients with stroke	14 participants right hemiparesis patients with stroke (blocked vs. random)	1	spooning stones task (mean time of spooning)	same day, 3 weeks (cornflakes instead of stones)	EV
1	2013	Kakar et al.	Effect of external and internal focus of attention on acquisition, retention,	24 patients with Parkinson's disease (internal focus vs external focus)	1	throw darts at a target	24 hours (distance increased by 1m)	MI

			and transfer phase of motor learning in Parkinson's disease					
1	2011	Kantak et al.	Transfer of motor learning engages specific neural substrates during motor memory consolidation dependent on the practice structure.	59 healthy participants (constant vs. variable practice)	0	forearm lever (RMSE)	24 hours (outside range of practice parameters)	CP
1	2018	Krishnan et al.	Learning new gait patterns: Age-related differences in skill acquisition and interlimb transfer	44 participants (young vs. older)	2	new gait pattern via foot trajectory task (tacking error %)	24 hours (untrained leg)	AN
1	2011	Langan & Seidler	Age differences in spatial working memory contributions to visuomotor	18 young vs. 18 older adults	2	joystick adaptation task (RT, error)	24 hours (rotated feedback display)	FB

			adaptation and transfer.					
1	2016	Lohse et al.	Engaging environments enhance motor skill learning in a computer gaming task	40 participants (engaging game group vs. less engaging sterile group)	0	Computer game Microsoft Kinect (points per block)	5-9 days (opposite condition)	MI
1	2016	Loranger et al.	Correlation of expertise with error detection skills of force application during spinal manipulation learning	63 participants (1st years, 4th years, 5th years, experienced chiropractors)	4	10 consecutive trials of their best spinal manipulations on a device	same day (from previous experience)	EX
1	2018	Meira & Fairbrother	Ego-oriented learners show advantage in retention and transfer of balancing skill	(Ex. 1) 56 college students (high ego-oriented vs. low ego-oriented) (Ex. 2) 48 college students (task orientation vs. ego orientation)	0	stand on a stabilometer (time in balance)	24 hours (different stance)	TT
1	2012	Mendes et al.	Motor learning, retention and transfer after virtual reality-	16 participants with early-stage Parkinson's disease vs. 11 healthy elderly controls	1	Wii Fit training	1 week, 60 days (functional reach test)	EV

			based training in Parkinson's disease: Effect of motor and cognitive demands of games					
1	2020	Moradi	Benefits of a guided motor-mental preperformance routine on learning the basketball free throw	45 undergraduate male students (5 step mental preperformance routine vs. self-regulated mental preperformance routine vs. no preperformance routine)	0	basketball free-throw (sum of points)	1 week (new shooting angle)	MI
1	2020	Nackaerts et al.	Retention of touchscreen skills is compromised in Parkinson's disease	11 Parkinson's disease vs. 10 healthy aged matched controls	1	swipe-slide pattern task finger movement (MT)	24 hours (untrained pattern)	TT
1	2019	Nemani et al.	Objective assessment of surgical skill transfer using non-invasive brain imaging	18 medical students (control vs. physical surgical trainer vs. virtual trainer groups)	4	laparoscopic cutting task (transfer task time)	2 weeks (laparoscopic cutting task on abdominal tissue instead of gauze)	EV

1	2020	Nunes et al.	Descriptive versus prescriptive feedback in the learning of golf putting by older persons	36 participants (verbal KP vs. video KP, both KP)	0	golf putting (AE, VE)	24 hours (different direction and distance)	FB
1	2018	Oppici et al.	The influence of a modified ball on transfer of passing skill in soccer	24 adult novices (futsal ball vs. soccer-ball control)	0	pass a moving ball with foot (performance accuracy)	48 hours (futsal ball)	EQ
1	2007	Orrell et al.	Implicit sequence learning processes after unilateral stroke	7 people with right hemisphere stroke vs. control 8 healthy participants	1	serial reaction time task (RT)	immediate, 2 weeks (whole arm movement on the big board)	AN
1	2015	Pekny & Shadmehr	Optimizing effort: increased efficiency of motor memory with time away from practice	41 participants (time away from practice 6 hours vs. 24 hours, 3 vs. 30 min)	0	out and back reaching movements (force index)	3 min, 30 min, 6 hours, 24 hours (other movements)	TT
1	2011	Pereira et al.	Effect of training on interlimb transfer of dexterity	169 participants (dominant vs. non-dominant hand training vs. control)	0	practical dexterity tasks like picking up rice and	1 month (other hand)	AN

			skills in healthy adults			putting in a container and screwing and unscrewing nuts and bolts (time take to perform common everyday skills)		
1	2019	Rajan et al.	Reciprocal intralimb transfer of skilled isometric force production	30 participants (arm training vs. hand training vs. no training)	0	robotic exoskeleton to control an on-screen cursor (time duration, success rate)	24 hours (switch to other group)	AN
1	2017	Riek et al.	A novel training device for tip control in colonoscopy: preliminary validation and	13 experienced colonoscopists vs. 16 novices	4	use a colonoscope to track 28 targets (completion time)	24 hours (different training surface)	EQ

			efficacy as a training tool					
1	2019	Ringhof et al.	Short-term slackline training improves task-specific but not general balance in female handball players	25 female handball players (slackline training vs. control)	4	slackline standing test (standing time)	6 weeks (standing test)	EX
1	2014	Rosalie & Müller	Expertise facilitates the transfer of anticipation skill across domains	(Ex. 1) 6 expert taekwondo, 6 near-expert taekwondo, 6 expert karate, 5 near-expert karate (E. 2) 8 expert and 5 near-expert footballers	4	execute a defensive response (accuracy of anticipation %)	same day (from previous experience)	EX
1	1994	Robertson et al.	The influence of skill and intermittent vision on dynamic balance	(Ex. 1) 10 female varsity gymnasts and 10 novices (Ex. 2) 9 female varsity gymnasts vs. 9 novices	4	balance beam walking (liquid crystal goggles eight conditions of varying intermittence of vision)	same day (other condition)	EX

1	2009	Roller et al.	Improvement of obstacle avoidance on a complaint surface during transfer	61 adults (lens-training sham vs. magnifying vs. reducing vs. up/down)	0	object avoidance walking	2 weeks (transfer to right-shift lenses)	FB
1	2017	Serrien et al.	Changes in balance coordination and transfer to an unlearned balance task after slackline training: a self-organizing map analysis	13 participants (slackline balance vs. flamingo balance)	0	slackline balance or flamingo balance (time)	5 days (flamingo or slackline balance)	TT
1	2015	Sharif et al.	Effects of physical and mental practice on motor learning in individuals with cerebral palsy	29 males with cerebral palsy (physical practice vs. mental practice vs. control)	1	dart throwing (scores)	48 hours (everyone does dart throwing from further distance)	MI
1	1976	Singer & Pease	A comparison of discovery learning and guided instructional	48 participants (guided, discovery, combination)	0	computer-managed novel serial	24 hours (discovery)	CP

			strategies on motor skill learning, retention, and transfer			manipulation task (time)		
1	2010	Van Ooteghem et al.	Aging does not affect generalized postural motor learning in response to variable amplitude oscillations of the support surface	21 healthy older adults (embedded-sequence vs. looped-sequence)	2	balance task required participants to stand on a hydraulically driven, servo-controlled platform that could be translated horizontally forward and backward (trunk variability ratio, COM mean phase, COM mean gain)	24 hours (random perturbations)	CP

1	2008	Vera et al.	Effects of different practice conditions on acquisition, retention, and transfer of soccer skills by 9-year-old school children	67 children aged 9 years old (blocked vs. variable vs. combined)	3	dribbling a soccer ball and kicking a soccer ball (score)	2 weeks (foam rubber ball)	EQ
1	1999	Vickers et al.	Decision training: The effects of complex instruction, variable practice and reduced delayed feedback on the acquisition and transfer of a motor skill	249 undergraduates (novice vs. intermediate vs. advanced baseball hitters) (behavioural training with simple to complex instruction, variable practice, lots of feedback vs. decision training with complex instruction, variable practice, reduced delayed feedback)	4	hit baseballs at 94 km/hr in a batting cage (% hits)	7 weeks (faster and slower speed)	FB
1	2013	Vine et al.	Gaze training improves the retention and transfer of	36 medical students (discovery learning vs. gaze training)	4	picking and dropping balls (completion	1 month (two-handed)	MI

			laparoscopic technical skills in novices			time, target locking score)		
1	2011	Wilson et al.	Gaze training improves technical performance and resistance to distractions in virtual laparoscopic surgery	30 medical trainees with no laparoscopic experience (gaze training vs. movement training vs. discovery learning)	4	eye-hand coordination task on VR laparoscopic surgical simulator (completion time, % time fixating, total path length)	same day (dual task distraction tone counting)	FB
1	1991	Wrisberg & Liu	The effect of contextual variety on the practice, retention, and transfer of an applied motor skill	52 elementary students (blocked vs. random)	3	badminton serves (mean accuracy score)	24 hours (opposite service area)	TT
1	2018	Yang et al.	Transferability of laparoscopic skills using the	44 surgical novices (VR vs. reality)	4	appendectomy training (total movements)	same day (both groups perform cholecystectomy on the simulator)	VE

			virtual reality simulator					

***Degree of specificity (1 = positive transfer)**

****Demographics (0 = healthy, 1 = rehabilitation/special population, 2 = aging, 3 = children, 4 = experts)**

*****Type of Transfer (EV = ecological validity transfer, AN = anthropometrical transfer, TT = target/task transfer, CP = conditions of practice transfer, ST = state transfer, EX = expertise transfer, FB = feedback modality transfer, VE = virtual environment transfer, MI = attention transfer, EQ = equipment transfer)**

2.12 Appendix D: Neutral Transfer

Specificity*	Year	Author	Title	Participants (Groups)	Demographics**	Motor task (measures)	Transfer duration (task)	Type of Transfer***
0	1973	Barnett et al.	Motor skills learning and the specificity of training principle	104 female students (fatigued vs. non-fatigued)	0	Moving an arm in a sigma like motion (time)	1 week (opposite as their trained condition)	ST
0	2018	Bootsma et al.	The role of task difficulty in learning a visuomotor skill	36 participants (low vs. medium vs. high task difficulty level)	0	star-tracing (error percentage, MT)	24 hours (to untrained difficulty levels)	TT
0	2016	Bouffard et al.	Pain induced during both the acquisition and retention phases of locomotor adaptation does not interfere with improvements in motor performance	39 university students (Pain vs. control group)	0	Treadmill walking adaptation task to an ankle perturbation (EMG)	24 hours (to walking without pain)	ST

0	2012a	(Boutin et al.	Practice makes transfer of motor skills imperfect	(Ex. 1) 30 Right-Handed undergraduates (repeated testing vs. non-repeated testing) (Ex. 2) 60 Right-Handed undergraduates (repeated + limited vs. repeated + prolonged vs. non-repeated + limited vs. non-repeated + prolonged)	0	horizontal arm lever waveform (RMSE)	10-min and 24 hours (to non-dominant arm)	CP
0	2012b	Boutin et al.	Testing promotes effector transfer	42 Right-Handed undergraduates (Early vs. Late Testing)	0	horizontal arm lever waveform (RMSE)	10-min and 24 hours (to original pattern)	TT
0	2017	Buszard et al.	Quantifying contextual interference and its effect on skill transfer in skilled youth tennis players (Ex. 2 only)	16 youth skilled tennis players (Low CI, moderate CI)	4	Serve "Down the T" (Serving accuracy)	1 week (in match play setting)	CP
0	2009	Elion et al.	No transfer of gains after a single training session within a	16 healthy young adults (virtual training, no-training)	0	maintain balance on a platform along virtual	24 hours, 4 weeks, 12 weeks (from virtual to perturbation)	VE

			virtual environment to fundamental tests of stability			road scenario and reaching for virtual objects (CoP)		
0	2016	Frömer et al.	Come to think of it: Contributions of reasoning abilities and training schedule to skill acquisition in a virtual throwing task	96 participants (blocked [low CI] vs. randomized [high CI])	0	Wii remote throws (performance)	1 week (further target distance)	CP
0	2012	Genzel et al.	Complex motor sequence skills profit from sleep	36 male volunteers (Group A arrived in the morning vs. Group B arrived in the evening)	0	DanceStage choreography with arrows PlayStation video game (Performance)	12 hours and 24 hours (new song)	ST
0	2019	Giboin et al.	Motor learning of a dynamic balance task: Influence of	32 young healthy participants (control vs. training)	0	3 balance tasks (seconds)	same day (to novel balance task)	TT

			lower limb power and prior balance practice					
0	2018	Giboin et al.	Additional intra- or inter-session balance tasks do not interfere with the learning of a novel balance task	(Ex. 1) 26 students intra-session training (tilt board group vs. tilt board and slack line group vs. control) (Ex. 2) 40 students inter-session training (tilt board group vs. tilt board and slack line vs. control)	0	tilt board balance task (balance performance)	24 hours (other balance training)	EQ
0	2017	Grzeczkowski et al.	Perceptual learning is specific beyond vision and decision making	58 participants (mouse vs. button press)	0	adjust the central line of vertical bisection task (mean offset)	24 hours (other group)	EQ
0	2006	Memmert	Long-term effects of type of practice on the learning and transfer of a complex motor skill	32 college students (constant vs. random training)	0	basketball shooting (shooting accuracy)	1 year (smaller handball)	CP

0	2018	Nemani	Convergent validation and transfer of learning studies of a virtual reality-based pattern cutting simulator.	18 medical students (control vs. FLS training vs. VBLaST training)	4	pattern cutting trials on their simulators (transfer task completion time)	2 weeks (ex vivo real tissue task)	EV
0	2019	Neva et al.	The effects of acute exercise on visuomotor adaptation, learning, and inter-limb transfer	17 young healthy participants (rest vs. exercise)	0	visuomotor rotation task right arm (peak lateral displacement, MT)	24 hours (left arm)	AN
0	2000	Nourrit et al.	The effects of required amplitude and practice on frequency stability and efficiency in a cyclical task	15 participants with no ski simulator experience (amplitudes of 15cm vs. 22.5cm vs. 30cm)	0	slalom ski-simulator (amplitude, frequency)	4 days (group 3 transfer to 15 and 22.5cm amplitudes)	TT
0	2020	Paul et al.	Dopamine replacement improves motor learning of an upper	23 participants with mild-moderate PD (train "on" vs. train "off" medication)	1	non-dominant functional motor task kidney bean	9 days (on medication, peg transfer task and functional task)	ST

			extremity task in people with Parkinson disease			scooping into cups (trial time)		
0	2018	Paul et al.	Dopamine replacement medication does not influence implicit learning of a stepping task in people with Parkinson's disease	37 participants with PD ("on" vs. "off" medication)	1	stepping task (response time)	9 days (untrained balance task)	TT
0	2016	Raastad et al.	Effect of practicing soccer juggling with different sized balls upon performance, retention, and transfer to ball reception	22 adolescent soccer players (small ball vs. big ball)	4	soccer ball juggling (time to control ball, reception distance, # of repetitions)	6 weeks (back to regular ball)	EQ
0	1996	Robertson & Elliott	Specificity of learning and dynamic balance	20 female physical education students (full-vision condition eyes open vs. no-vision	0	walk as quickly as possible without	5 days (switch group)	FB

				condition blackened ski goggles)		stepping off the balance beam (time, # of steps, form errors)		
0	2004	Robin et al.	Sensory integration in the learning of aiming toward "self-defined" targets	36 students (proprioceptive vs. both visual and proprioceptive) (20 trials vs. 720 trials)	0	moving a hand-held stylus	24 hours (other group)	FB
0	2010	Rochester et al.	Evidence for motor learning in Parkinson's disease: Acquisition, automaticity and retention of cued gait performance after training with external rhythmical cues	153 participants (auditory cues vs. visual cues vs. somatosensory cues) (single vs. dual tasks)	1	gait training (speed, step length)	6 weeks (transfer to no cues)	FB
0	2015	Romkema et al.	Intermanual transfer effects in upper-limb prosthesis training: The	64 able-bodied participants (short and long interval training vs. short and long interval control groups)	0	functional grip tasks and a grip-force	11 days, 17 days, 22 days (other hand)	AN

			influence of inter-training intervals			control task (MT, N)		
0	2014	Sanli & Lee	What roles do errors serve in motor skill learning? An examination of two theoretical predictions.	(Ex. 1) 19 young adults (Ex. 2) 20 young adults	0	propel a small disc over tabletop (proportion of errors, radial error)	24 hours (Ex 1. new target size) (Ex. 2 new target location)	TT
0	1987	Seitz & Wilson	Effect on gait of motor task learning acquired in a sitting position.	31 adults (control vs. short-rhythm vs. long-rhythm)	0	heel up heel down rhythm task (heel off time)	24 and 48 hours (to gait pattern)	AN
0	1990	Stanley & Franks	Learning to organize the frequency components of a perceptual motor skill.	(Ex. 1) 4 students (Ex. 2) 6 students	0	joystick to move a cursor on oscilloscope screen (amplitude)	3 months (new waveform)	TT
0	2003	Teixeira & Caminha	Intermanual transfer of force control is modulated by asymmetry of	29 university students (symmetric force vs. asymmetric force vs. control)	0	launching a small cart across a track with the	48 hours (other hand)	AN

			muscular strength			preferred hand (Variability, error)		
0	2016	van der Kooij et al.	Temporally stable adaptation is robust, incomplete and specific	12 participants (Predicted vs. vision vs. proprioception)	0	pointing task (direction degrees)	1 week (other hand)	AN
0	2000	Weigelt et al.	Transfer and motor skill learning in association football [soccer].	20 intermediate male football [soccer] players (4-week training vs. control)	4	juggled a football [soccer ball] as many times as possible in 30 seconds (mean number)	4 weeks (other leg)	EX
0	2018	Willey & Liu	Long-term motor learning: Effects of varied and specific practice	30 adults (specific vs. varied)	0	beanbag throwing task (signed error, absolute error, variance)	1 week (longer and shorter distances)	TT
0	2015	Wu et al.	Learning to combine high	8 adults	0	4-finger accurate	2 weeks (grasping task)	TT

			variability with high precision: lack of transfer to a different task			force production task (RMSE)		
0	2020	Yamada et al.	The Effects of Using Imagery to Elicit an External Focus of Attention	42 healthy male participants (cone-present vs. cone-imagined)	0	standing long jump (average jump distance)	24 hours (switch conditions)	MI
0	2017	Yokoi et al.	Restricted transfer of learning between unimanual and bimanual finger sequences.	32 healthy participants (unimanual sequence A&B vs. unimanual sequence C&D vs. bimanual A1&B2 vs. bimanual sequences C3&D4)	0	discrete sequence production task with fingers (MT)	24 hours (other sequences)	AN
0	2018	Zech et al.	Effects of barefoot and footwear conditions on learning of a dynamic balance task: a randomized controlled study	60 healthy adults (barefoot vs. shod vs. control)	0	stability platform (seconds)	1 week (other condition)	EQ

***Degree of specificity (0 = neutral transfer)**

****Demographics (0 = healthy, 1 = rehabilitation/special population, 2 = aging, 3 = children, 4 = experts)**

*****Type of Transfer (EV = ecological validity transfer, AN = anthropometrical transfer, TT = target/task transfer, CP = conditions of practice transfer, ST = state transfer, EX = expertise transfer, FB = feedback modality transfer, VE = virtual environment transfer, MI = attention transfer, EQ = equipment transfer)**

2.13 Appendix E: Negative Transfer

The 19 experiments from the 135 articles were included in this scoping review with evidence of negative transfer.

Specificity*	Year	Author	Title	Participants (Groups)	Demographics**	Motor task (measures)	Transfer duration (task)	Type of Transfer***
2	2010	Breslin et al.	An especial skill: Support for a learned parameters hypothesis	10 expert basketball players vs. 10 novices	4	Free throw regular ball vs heavy ball (3-point system)	Same day (previous experience)	EQ
2	2001	Coull et al.	Examining the specificity of practice hypothesis: Is learning modality specific?	(Ex. 1) 40 university students (vision + 10 trials vs. vision + 100 trials vs. audition + 10 trials vs. audition + 100 trials). (Ex. 2) 50 university students (vision vs. audition vs. vision + audition but attend to the vision vs. vision + audition but attend to the audition vs. vision + audition no instruction)	0	isometric handheld dynamometer (RMSE)	48 hours (switch to opposite condition)	FB

2	2013	Czyz et al.	Especial skill effect across age and performance level: The nature and degree of generalization	37 male basketball players (2 groups of senior players, cadet group, junior group)	4	free throw shots from 7 distances, including the free throw line (% of success)	Same day (previous experience)	EX
2	2013	Fay et al.	An especial skill in elite wheelchair basketball players	12 elite male basketball players	4	basketball shot from 5 different distances (accuracy)	Same day (From previous sport experience)	EX
2	1969	Hammerton & Tickner	Some factors affecting learning and transfer of training in visual-motor skills.	(Ex. 1) 12 participants royal naval ratings (condition A, with the control correctly orientated to body (forearm) and to space (display); B, control correctly orientated to body but not to space; and C, control correctly orientated to space but not to body)	4	thumb-joystick to perform an acquisition task which was presented to them on a cathode-ray tube, and that the control/display relations could be	24 hours (transferred to condition C)	FB

						modified to give three experimental conditions		
2	1964	Hammerton & Tickner	Transfer of training between space-oriented and body-oriented control situations.	24 royal naval ratings (A control task was set up which could be correctly oriented: A, both bodily and spatially; B, bodily but not spatially; C, spatially but not bodily)	4	thumb-joystick from the Applied Psychology Research Unit control simulator	24 hours (Transfer was studied in four cases: (1) condition A to condition B, (2) B to A, (3) A to C, (4) C to A.)	FB
2	2019	Healy et al.	Training, retention, and transfer of data entry perceptual and motor processes over short and long retention intervals	(Ex. 1) 24 undergraduate students (Ex. 2) 26 undergraduate students	0	data entry keypress task (execution time)	(Ex. 1) 2 days, (Ex. 2) 8 months (change-hand test, change-stimuli test)	AN
2	2016	Helm et al.	Domain-specific and unspecific reaction times in experienced team handball	30 participants (15 handball goalkeepers vs. 15 novices)	4	domain-unspecific simple or choice stimulus–	Same day (From previous sport experience)	EX

			goalkeepers and novices			response (CSR) tasks as well as CSR tasks that were domain-specific only for goalkeepers		
2	1999	Hodges & Lee	The role of augmented information prior to learning a bimanual visual-motor coordination task: Do instructions of the movement pattern facilitate learning relative to discovery learning?	33 participants (General instruction group vs. specific instruction group vs. no instruction and secondary task learning groups)	0	Bimanual wooden handles linear slide (ACE)	24 hours (new pattern)	MI
2	2014	Moradi et al.	Specificity of learning a sport skill to the visual	28 male high school students (full vision vs. target-only vision)	0	basketball free-throw (sum of points)	2 hours, 10 days (other condition)	FB

			condition of acquisition					
2	2019	Moufti & Arfaoui	Kinematic analysis of the "attack to the legs" from wrestling: impact of prior judo expertise	10 male participants (7 years' experience vs. practice wrestlers but with judo experience)	4	attack to opponents' legs (angle, speed)	10 weeks (skill from previous expertise)	EX
2	2007	Movahedi et al.	A practice-specificity-based model of arousal for achieving peak performance	37 male physical education students (high-arousal vs. low-arousal)	0	basketball free throw (mean scores)	10 days (other condition)	ST
2	1957	Nelson	Study of transfer of learning in gross motor skills	90 men in college physical education classes (Badminton & Tennis vs. Volleyball & Basketball vs. Track stance & Football stance)	4	paired sport training (score)	6 weeks (to other sport)	EX
2	2007	O'Keeffe et al.	Transfer or specificity? An applied investigation into the relationship	46 participants (fundamental overarm throw vs. badminton overhand clear vs.	0	badminton clear and javelin throw (mean score)	2 weeks (javelin throw)	EX

			between fundamental overarm throwing and related sport skills	control group no practice)				
2	2008	Onla-or & Winstein	Determining the optimal challenge point for motor skill learning in adults with moderately severe Parkinson's disease	20 Parkinson's disease vs. 20 healthy controls (low vs. high task difficulty) (low vs. high practice demand)	1	handle of a lever moves horizontally with goal MTs (RMSE)	24 hours (random retention)	CP
2	2010	Rozanov et al.	The specificity of memory for a highly trained finger movement sequence: Change the ending, change all	10 participants (sequence A)	0	finger opposition sequence (average time of sequence, # of errors)	3 weeks (new sequence, sequence omit a section)	TT
2	2009	Simons et al.	Challenges to cognitive bases for an	7 college pitchers	4	pitching distances (accuracy	same day (from previous experience)	EX

			especial motor skill at the regulation baseball pitching distance			score, % strike)		
2	2013	Stoeckel & Breslin	The influence of visual contextual information on the emergence of the especial skill in basketball	36 experienced basketball players (-30 set up so the free throw line is further, regular court, +30 set up)	4	basketball free throw (percent success)	same day (previous expertise)	EX
2	2010	Yamaguchi & Proctor	Compatibility of motion information in two aircraft attitude displays for a tracking task	40 undergraduate students (horizon moving vs. aircraft moving displays)	0	attitude tracking task (mean RT)	24 hours (switch conditions)	FB

***Degree of specificity (2 = negative transfer)**

****Demographics (0 = healthy, 1 = rehabilitation/special population, 2 = aging, 3 = children, 4 = experts)**

*****Type of Transfer (EV = ecological validity transfer, AN = anthropometrical transfer, TT = target/task transfer, CP = conditions of practice transfer, ST = state transfer, EX = expertise transfer, FB = feedback modality transfer, VE = virtual environment transfer, MI = attention transfer, EQ = equipment transfer)**

2.14 Appendix F: Mixed Results

Specificity*	Year	Author	Title	Participants (Groups)	Demographics**	Motor task (measures)	Transfer duration (task)	Type of Transfer***
3	2017	Al-Saud et al.	Feedback and motor skill acquisition using a haptic dental simulator	63 novices (device only feedback vs. verbal feedback from dental instructor vs. combination)	0	Dental simulator drill out target area of shape (task completion, drill time, error scores)	Immediately after training (Transfer to novel shape)	FB
3	1995	Bard et al.	The transfer of perceptual and/or motor training to the performance of a coincidence-anticipation task	55 children (throw vs. button vs. throw and button [criterion task])	3	target throw or button anticipation task (constant temporal error, throw initiation time, throw duration, absolute spatial	Day 2 in the afternoon (everyone transfers to criterion task slide throw)	FB

						errors, mean error)		
3	2010	Cohen & Sekuler	Chunking and compound cueing of movement sequences: learning, retention, and transfer	24 participants (chunk learning vs. whole series learning)	0	Stylus on graphics tablet (Error and RT)	24 hours (reorder, novel sequence)	CP
3	2019	Cole & Shields	Age and cognitive stress influences motor skill acquisition, consolidation, and dual-task effect in humans	64 participants (Young vs. Old) (Control 1, Control 2, Dual Task 1, Dual Task 2)	2	Stand on one foot and maintain light fingertip contact with apparatus. Single leg squat match knee line to target line (% error) with cognitive dual task	24 and 48 hours (new resistance and velocity)	TT
3	2000 a	Dick et al.	Contextual interference and motor	84 Alzheimer's disease patients and 72 healthy controls (constant,	1	beanbag toss (score)	2-4 days (heavy bean bag for near transfer,	EQ

			skill learning in Alzheimer's disease	variable-parameter, variable-program, variable-combined, no training)			horseshoe for intermediate transfer)	
3	2000b	Dick et al.	The variability of practice hypothesis in motor learning : does it apply to Alzheimer's disease?	58 Alzheimer's disease patients, 58 healthy controls (constant, random, blocked, no practice)	1	beanbag toss (score)	2-4 days (heavy bean bag for near transfer, horseshoe for intermediate transfer)	EQ
3	1999	Ferrari	Influence of expertise on the intentional transfer of motor skill	20 karate students (10 experts vs. 10 novices)	4	learned the first stage in Old Yang-style tai chi (# of component gestures present, # of movements remembered, quality of performance)	From previous sport experience	EX
3	1949a	Gagne & Foster	Transfer to a motor skill from	145 Navy enlisted men (0, 8, 16, 24, 48 trials groups)	4	paper and pencil mark on 'X' on the	same day (transfer to pressing a switch)	EV

			practice on a pictured representation			switch vis stimuli (# of errors)		
3	1949b	Gagne & Foster	Transfer of training from practice on components in a motor skill.	170 Navy enlisted men (group 0, 10, 30, 50, 30B with different corresponding switch instructions)	4	pressing a switch (# of errors)	same day (four switches)	TT
3	2019	Grzeczkowski et al.	Motor response specificity in perceptual learning and its release by double training	38 participants (button press vs. mouse adjustment	0	3-line bisection task button push (adjusted offset)	24 hours (other hand)	AN
3	2005	Heitman et al.	Effects of specific versus variable practice on the retention and transfer of a continuous motor skill	30 participants (variable speed vs. specific speed vs. control)	0	rotary pursuit (time on target)	48 hours (transfer speed)	CP
3	2010	Herpin et al.	Sensorimotor specificities in balance control of expert fencers and pistol shooters	12 expert fencers, 10 expert shooters, 10 sedentary controls	4	Sensory Organization Task (sway path, area)	From previous sport experience	EX

3	2001	Jarus & Gutman	Effects of cognitive processes and task complexity on acquisition, retention, and transfer of motor skills	96 children (blocked vs. random vs. combined) (on a complex vs. simple task)	3	throw beanbags at three target circles (time)	24 hours, simple transfer vs. complex transfer task (bean bag size order change and target order change)	CP
3	2005	Keetch et al.	Especial skills: Their emergence with massive amounts of practice	(Ex. 1) 8 male college basketball student athletes (ex. 2) 8 female basketball players (Ex. 3) Same participants as Experiment 2	4	(Ex. 1 & 2) basketball shooting task from foul line (% success) (Ex. 3) jump shot (% success)	24 hours (other distances than they are used to)	EX
3	2020	King et al.	Does training in the cold improve cold performance?	20 participants (cold vs. thermoneutral)	0	grooved pegboard task (time)	24 hours (to opposite temperature)	ST
3	2020	Logishetty et al.	Fully immersive virtual reality for total hip arthroplasty: objective	32 orthopaedic residents surgical postgrads vs. expert	4	VR surgical task (errors, prompts asked)	From previous real experience	VE

			measurement of skills and transfer of visuospatial performance after a competency-based simulation curriculum					
3	2009	Maslovat et al.	Feedback effects on learning a novel bimanual coordination pattern: support for the guidance hypothesis	12 university aged participants (continuous feedback vs. discrete feedback)	0	bimanual coordination manipulandum pattern (Absolute error of relative phase ABSE)	2 days, 1 week (different feedback condition)	FB
3	2004	Maslovat et al.	Contextual interference: Single task versus multi- task learning	30 right-handed participants (blocked vs. random vs. control)	0	bimanual coordination manipulandum pattern (RMSE)	2 days, 1 week (different feedback condition)	FB
3	2019	Marcolin et al.	Expertise level influences postural balance	7 basic level gymnasts vs. 8 advanced level gymnasts	4	balance two feet, balance one foot, roundoff,	same day (from previous experience)	EX

			control in young gymnasts			back-handspring (sway)		
3	2014	Morin-Moncet et al.	BDNF Val66Met polymorphism is associated with abnormal interhemispheric transfer of a newly acquired motor skill	20 participants (genotype Val66Met vs. genotype VAl66Val)	0	serial reaction time task (RT)	1 week (other hand)	AN
3	1969	Prather	The effects of trial-and-error or errorless training on the efficiency of learning a perceptual-motor skill and performance under transfer an d stress	96 male student pilots from air force base (trial and error vs. errorless)	4	press trigger button when estimated that the target was in open fire range for the trial-and-error group or press the trigger when the green light comes on for	same day (stress, photograph target transfer)	EV

						errorless (error)		
3	2010	Ranganathan & Newell	Motor learning through induced variability at the task goal and execution redundancy levels	32 volunteers (constant group vs. variable group) (low-redundancy vs. high-redundancy)	0	pen on a digital tablet (AE, variability)	24 hours (transferred to fixed or variable target)	CP
3	2014	Ranganathan et al.	Learning redundant motor tasks with and without overlapping dimensions: facilitation and interference effects.	50 healthy adults (prior task either shared vs. Did not share the mapping of the criterion task)	0	data glove for virtual reaching task mapped onto an on-screen cursor (MT, error)	24-48 hours (criterion task)	TT
3	2018	Rhein & Vakil	Motor sequence learning and the effect of context on transfer from part-to-whole and from whole-to-part	87 undergraduate students (whole vs. part sequence)	0	serial reaction time task (RT)	24-48 hours (switch groups)	TT
3	2018	Ringhof & Stein	Biomechanical assessment of dynamic	24 healthy young female gymnasts vs. swimmers	4	recover balance as quickly as	same day (from previous experience)	EX

			balance: Specificity of different balance tests			possible (time to stabilization)		
3	2017	Romkema et al.	Influence of the type of training task on intermanual transfer effects in upper-limb prosthesis training: A randomized pre-post-test study	71 able-bodied participants (reach training, grasp training, force control training, functional training, vs. sham vs. no-training)	0	prosthesis simulator on the training arm	11 days (other hand)	AN
3	2004	Seidler	Multiple motor learning experiences enhance motor adaptability.	33 participants (multiple learning 1 vs. multiple learning 2)	0	basic joystick aiming task (error, RT)	24 hours (perturbation trials)	TT
3	1979	Shea & Morgan	Contextual interference effects on the acquisition, retention, and transfer of a motor skill	72 right-handed participants (blocked low interference vs. random high interference)	0	grasp a tennis ball and knock down specific barriers (total time)	10-min, 10-day (switch condition)	CP

3	2016	Steinberg et al.	Mirror visual feedback training improves intermanual transfer in a sport-specific task: a comparison between different skill levels	39 basketball and handball players vs. 41 novices (mirror visual feedback vs. direct feedback)	4	stationary basketball dribble task	24 hours (other hand)	AN
3	2012	Stockel & Weigelt	Brain lateralisation and motor learning: selective effects of dominant and non-dominant hand practice on the early acquisition of throwing skills	(Ex. 1&2) 16 children aged 11-14 right-handed (practice non-dominant first, counterbalanced)	3	(Ex. 1) basketball throwing (points) (Ex. 2) Handball throwing	2 weeks (switch hands)	AN
3	2015	Verneau et al.	Proactive and retroactive transfer of middle age adults in a sequential motor learning task	19 young adults vs. 18 middle aged adults	2	assembly task (accuracy, MT)	24 hours (different assembly order)	TT

3	2002	Williams et al.	Age-related differences in vision and proprioception in a lower, limb interceptive task: The effects of skill level and practice	(Ex. 2) 18 12-year-old less-skilled soccer players	3	control a soccer ball in full light or no light (score)	1 week (switch conditions)	FB
3	2017	Yeganeh Doost et al.	Two processes in early bimanual motor skill learning	51 participants (long circuit 1 vs. long circuit 2 vs. switch circuit 1/2 vs. switch circuit 2/1 vs. short circuit 2)	0	bimanual robotic manipulandum to guide a cursor across a complex circuit (amount of improvement)	24 hours (new circuit)	CP

***Degree of specificity (3 = mixed results)**

****Demographics (0 = healthy, 1 = rehabilitation/special population, 2 = aging, 3 = children, 4 = experts)**

*****Type of Transfer (EV = ecological validity transfer, AN = anthropometrical transfer, TT = target/task transfer, CP = conditions of practice transfer, ST = state transfer, EX = expertise transfer, FB = feedback modality transfer, VE = virtual environment transfer, MI = attention transfer, EQ = equipment transfer)**

CHAPTER 3: BRIDGING CHAPTER

3.1 Where we are now

Having examined the scope of literature in motor learning transfer studies, chapter two reveals that there are no clear boundaries of when practicing a motor task will be more likely to result in generalizability or specificity of practice. After creating this scoping review in the previous chapter, there are still no clear answers about when the learning of a motor task can be generalizable to the learning of another motor task, or when it will be too specific. Leaving the fourth research question (i.e., to determine if there exists any commonality between the taxonomy and transfer test outcome that points toward motor training protocols that are more likely than not to lead to generalizability or specificity of practice) in chapter two without definitive answers is disappointing, nonetheless a realistic reflection of the literature.

3.2 What we can do moving forward

What we can do moving forward in this area of motor learning transfer test literature is to use the checklist outlined at the end of chapter two to aid in our mindfulness of some methodology considerations. To further that, in the following chapter, a motor learning transfer test experiment examines the transferability of a specific sensorimotor representation on a waveform hand tracking task as proof of protocol using the checklist outlined at the end of chapter two. Pre-emptively, the checklist is addressed in the following ways in chapter four:

- ☐ Follow a traditional motor learning experimental protocol using acquisition, immediate retention test, delayed retention test (greater than or equal to 24 hours later), and transfer test

This first point is addressed in chapter four by having an acquisition period where participants practice the novel waveform hand tracking task over 80 trials with feedback of seeing their trace overlapped with the goal trace after every trial. The same motor task is then completed for 40 trials where no visual of the trace feedback is provided in an immediate retention test. Approximately 24 hours (± 1.82) later the exact same test as the immediate retention test was employed in a delayed retention test. Also on the second day, the transfer test was employed by transferring only the sensorimotor experience for participants. Considering the measures taken above, these satisfy the first item on the checklist.

- ☑ Follow a traditional motor learning experimental protocol using acquisition, immediate retention test, delayed retention test (greater than or equal to 24 hours later), and transfer test

The next item on the checklist relates to the transfer test properties:

- ☐ Understand and clearly state the intentions of the transfer test, and the exact element being transferred. (What differs the transfer test from the delayed retention test, and select only one element to change)

This item will differ between studies depending on the research question, but the concept of only transferring one element should remain. In the context of the study in chapter four, the sensorimotor experience of physical fatigue of the arm is being examined. With this in mind, the transfer test consists of the exact same motor task as the delayed retention test, except under an opposite condition of physical fatigue (either with or without physical fatigue). This clearly establishes that the intention of the transfer test is to test for the generalizability or specificity of practice under the opposite condition of physical fatigue that the motor task was practiced. It is also established that the only element to change in the transfer test from the delayed retention test is the physical fatigue condition. The motor task itself remains the exact same. Based on these measures, they fulfill the second requirement on the checklist.

- ☑ Understand and clearly state the intentions of the transfer test, and the exact element being transferred. (What differs the transfer test from the delayed retention test, and select only one element to change)

The next item on the checklist relates to the independent and/or dependent variables to be examined:

- ☐ Utilize the minimum number of independent and/or dependent variables of interest suitable for the motor task and research question being used

This item will also differ between studies depending on the research question, but the concept remains that the minimum number of variables should be used to better isolate the results. The novel waveform tracking task that is used in chapter four can be performed with improvements seen either in the participants' speed of completion and/or in the participants' accuracy. With that in mind, the experiment in chapter four examines the speed and accuracy measure typically used when assessing the learning of an accuracy constrained motor task. The conciseness of having only the minimum number of independent and dependent variables of interest represented can help clarify the main findings of the main research question. According to these measures, the third requirement on the checklist has been met.

☑ Utilize the minimum number of independent and/or dependent variables of interest suitable for the motor task and research question being used

The next item on the checklist relates to using the Transfer Taxonomy:

☐ Utilize the Transfer Taxonomy language to allow for more consistent conclusion language being used in the motor learning literature

This item should be applicable across all future motor learning transfer test studies. This item related to item number two on the checklist and is a good way to double-check that there is only one aspect of what has been learned is being transferred. Once the three prior items on the checklist have been completed, this fourth item is a good way to then categorize the style of study. If the three prior items have been accomplished, then this fourth item should be fitting to finalize the conciseness of the study. The study in chapter four fits into the State Transfer category of the Transfer Taxonomy as the element that is attempting to transfer is the participant’s practice under the condition of physical fatigue. The physical fatigue that the participants practice under is a state that participants experience and can be manipulated in the study to various levels (i.e., physical fatigue or no-physical fatigue). Based on this classification and the language used, this fulfills the final criteria on the checklist.

☑ Utilize the Transfer Taxonomy language to allow for more consistent conclusion language being used in the motor learning literature

3.3 Connecting Chapter 2 and Chapter 4

The scoping review in chapter two identifies the motor learning studies that support either the generalizability or the specificity of practice hypotheses and examines any commonality in the type of transfer within them. From the scoping review, 49 positive transfer studies support generalizability, 34 neutral transfer studies support a minor level of specificity of practice, 19 negative transfer studies support the specificity of practice hypothesis and 33 mixed results studies were found, but with minimal commonalities. Part of the reason for a lack of consistent conclusions among motor learning studies with transfer tests is the deficiency of structure and organization in this field of research. After understanding the limitations in motor learning specificity experiments, the above checklist items can be used to design a specificity of motor learning study to isolate the hypothesis. Using the above checklist, an appropriate protocol will be used to examine one of the rarer types of transfer seen in negative transfer, state transfer. A protocol has been designed to examine state transfer and to create one of the most robust sensorimotor representations under a state condition. Chapter four will employ the checklist above to demonstrate the most effective way to assess motor learning generalizability or specificity.

CHAPTER 4: THE SPECIFICITY OF PRACTICING A MOTOR TASK UNDER PERIPHERAL FATIGUE: AN INVESTIGATIVE FRAMEWORK

4.1 Abstract

This chapter develops an investigative framework to guide future state transfer motor learning studies. We create a specific sensorimotor learning context, and when this context is replaced with a different sensorimotor context, we hypothesize a decrement in performance typically seen in a speed-accuracy trade-off (Fitts, 1954). The checklist reported in chapter two is employed and tested in this chapter and results are discussed in the context of state transfer motor learning studies from a framework perspective. The specificity of practice hypothesis (e.g., Proteau, 2005; Proteau et al., 1987, 1992, 1998; Proteau & Isabelle, 2002) suggests that, during the acquisition of a novel motor task, a learner develops a sensorimotor representation for that task that is so specific, the learner will often experience negative transfer when performing the task in a novel context or environment. In the study reported here, thirty-six healthy adults aged adults 18-35 (55.6% female) were randomized into either physical fatigue or no-physical fatigue groups. The physical fatigue group underwent a forearm fatiguing protocol on their dominant arm prior to, and throughout the acquisition, immediate retention, and delayed retention phases of the motor learning task (the no-physical fatigue group did not). Participants were tasked with recreating a mouse trackpad waveform with their fifth digit on their dominant hand, the performance of which was assessed by root mean square error (accuracy) and movement time (speed). The transfer tests (both immediate and delayed) involved the same motor task but required participants to switch to the opposite

sensorimotor condition (physical fatigue or rest) that they practiced under. For speed, there was neither a main effect for condition, nor a group by block interaction. For accuracy, there was a main effect for condition, however, there was no group by test interaction. These results suggest that the speed and accuracy of participants' motor performance on transfer tests did not change, regardless of the condition they practiced under. Overall, no relationship was found between movement time and root mean square error at any stage of performance on the motor task for either group. This lack of correlation data suggests participants were not engaging in the speed-accuracy trade-off under the conditions of physical or no-physical fatigue and neither group was affected by the change in the sensorimotor context. The framework itself stands as a solid suggested method from the checklist in chapter two for designing state transfer motor learning studies.

4.2 Introduction

4.2.1 Preamble

Based on the findings of limitations addressed in detail in chapter two, a subsequent checklist was developed that itemized recommended protocol practices to be followed (see chapter two 'Checklist for transfer test studies'). This chapter reports the framework of a study where we implement this checklist as a methodological "guide" intended to recognize and forestall some of the conceptual and procedural limitations that we argue have led to the inconsistency in results and conclusions that comprise the current literature in motor learning transfer studies. It is important to note here that the primary purpose of this study is to present suggestions for methodological structure for future studies in this area. This study is not intended to provide additional causal insights into the specificity of practice /transfer phenomenon per se. In order to do so, appropriate power calculations would have required the collection of data from up to 106 participants for a 100% information rate based on a Pocock alpha spending function (see Appendix J). Satisfying these requirements would extend this thesis chapter beyond the scope of its purpose. For this reason, data collection was halted at a point where sufficient data were collected to allow only for preliminary analyses. With this caveat in mind, our final sample size of 36 participants is consistent with, and in fact often exceeds, the sample sizes of experimental studies that comprise the specificity of practice literature. For this reason, we completed, report, and interpret statistical analyses on our data to serve as a point of comparison with other studies in the literature.

4.2.2 Background

For many decades, researchers in motor learning have been studying how well humans retain and apply motor skills, both to extend the theory on these issues as well to understand how these theories may be best applied to a variety of applied motor skill learning situations. When assessing if a motor skill has been learned effectively, it is often useful to assess the performance of that skill in a novel environment or context that differs from the original practice conditions (termed a transfer test). If performance on the transfer task was better than it would have been had the original practice not taken place, it can be inferred that the perceptual-motor mechanisms developed during the original practice included at least some degree of generalizability to the new situation or context. If performance on the transfer task is worse following the original practice (i.e., participants who had not practiced the original task perform better than those who had), it can be inferred that the perceptual-motor mechanisms developed under the original practice conditions are maladaptive to the new situation. This is termed negative transfer and is considered to be evidence that learning is specific to the original practice context. As such, and regardless of the outcome measures of the motor task, there are really only three possible outcomes in motor learning studies: evidence of positive transfer (generalizability), neutral transfer, or evidence of negative transfer with the latter two of these suggesting learning specificity.

4.2.3 Positive Transfer

Motor learning studies, and chapter two of this thesis, suggest that being able to generalize the learning of a motor task (positive transfer) to a novel environment suggests that the motor task has been learned. Observation of a positive transfer result suggests that there is a benefit to learning the initial motor task, and this learning helps the individual in the performance of a different motor task with similarity in skill or context. One example of positive transfer from chapter two by Bested and colleagues (2019) compared robotic guidance to no guidance on a golf putting task and found the learning of this motor task generalizable to a different target and a new putter. Though the learning of that golf putting task was found to have generalizable results, isolating the transfer to only one changed element would have been best (i.e., either changing the target or changing the putter, not both at once). The message here, however, is the learning of the golf putting task either with or without the robotic guidance had a positive transfer to also golf putting but to a new target and with a new golf putter. Between the learning of the motor skills in this evidence of positive transfer, there is a similarity in the motor skill with both tasks being golf putting tasks.

4.2.4 Neutral Transfer

Another possible outcome from a learned motor task to a transfer task is a situation where there is no observable performance benefit in the transfer task following the acquisition of the original or previous task. In this case, the transfer can be considered neutral (i.e., no observable benefit or cost from having practiced the original task). An example of neutral transfer from chapter two is from Raastad and colleagues (2016) who examined soccer players juggling a small (compared to a large) soccer ball and found neutral change when transferring back to a regular-sized soccer ball. In this example of neutral transfer, practice appears to be specific to the original task (i.e., juggling the small soccer ball and the big soccer ball) such that performance is neither better nor worse in the transfer condition (i.e., juggling the regular soccer ball). Rather, it is simply a case of the original practice having no observable influence on the performance of this latter task (i.e., performance would have been the same whether the training on the different-sized balls took place or not).

4.2.5 Negative Transfer

The third possible, and least likely outcome (see chapter two of this thesis), is negative transfer. In situations of negative transfer, learning is so specific to the initial task, that the perceptual-motor mechanisms developed during original task acquisition have an observably detrimental effect on the performance of the second task (i.e., the learner would have been better served by not learning the original task at all). An example of negative transfer from chapter two by Fay and colleagues (2013) examined elite wheelchair basketball players with their learned motor skill being their expertise at shooting the basketball from the free throw line distance. When the basketball players shot from five different distances, there was a negative transfer seen in the performance at the different distances compared to the acquired free-throw line distance. Results of the review comprising chapter two of this thesis demonstrate that negative transfer is relatively rare, and within the negative transfer category, expertise and feedback modality seem to be the most common sources of negative transfer effects. Other, more rare, initial practice conditions resulting in negative transfer as described in the taxonomies outlined in chapter two include anthropometrical, target/task, conditions of practice, state, attentional, and equipment transfer. It should also be noted that from the taxonomy classifications in chapter two, state transfer was the only taxonomy category that failed to elicit positive transfer (four studies of neutral transfer [Barnett et al., 1973; Bouffard et al., 2016; Genzel et al., 2012; Paul et al., 2020], one study of negative transfer [Movahedi et al., 2007], one study of mixed results [King et al., 2020]). Considering the evidence above with state transfer demonstrating minimal (neutral transfer) to extensive (negative transfer) specificity of practice, the state transfer taxonomy space is investigated further in this chapter. State transfer is the focus of this discussion as it was a taxonomy category with limited representation, and it demonstrated polarizing results. First, a brief review of the studies within the state transfer taxonomy is outlined below.

4.2.6 State Transfer Taxonomy: Neutral Transfer

Within the category of state transfer from the taxonomy in chapter two, neutral transfer results were found in four studies. Neutral transfer was found in a study between fatigued and non-fatigued groups prior to performing an axel rotating arm task (Barnett et al., 1973). The fatiguing condition consisted of participants exercising on a horizontal arm ergometer and the non-fatigued condition did a finger-tapping task. For a transfer test, groups switched conditions. Results of this experiment found no interaction between conditions indicating that it did not matter which condition participants practiced the motor task under for performance under the opposite condition of fatigue. A limitation of this work is the lack of consideration using the speed-accuracy trade-off principle. Since only movement time (MT) was measured, it is possible that a change in performance occurred with the participant's accuracy throughout the fatigue transfer.

Additional evidence of neutral transfer for state transfer was found by Bouffard and colleagues (2016) where participants were either in pain (topical cream applied) or a control group in learning a treadmill walking ankle perturbation adaptation task. Results of the study revealed no significant differences between the pain and no pain groups when transferring to the opposite condition on a locomotion adaptation task. This suggests that cutaneous pain does not impact global walking adaptation performance. The authors discussed that it is unlikely that the participants learned to rely on the sensory feedback caused by the pain cream as the pain induced was tonic and unrelated to the movement. This cream application may be limited to impairing proprioceptive and cutaneous perception, which are still sources of feedback during the motor task, but not salient enough to create a difference in motor learning. A limitation of this study is having both groups start with no pain. This introduction to the same sensation contaminates the pain training group’s experience. To elicit a true sensorimotor experience, the time spent training should be under only one condition.

Evidence of neutral transfer in a state transfer were also revealed in a study by Genzel and colleagues (2012) who examined the effects of sleep levels on the learning of a video game *DanceStage* (PlayStation 2, Sony). Participants were randomly divided into either a condition that arrived in the morning, learned the dance task, and were retested in the evening and again in the morning, or a condition where participants arrived in the evening and were retested in the morning and again in the evening, respectively. When transferred to a new song, the results of this study demonstrated that there was a neutral transfer of the learned motor skills regardless of sleep and time of day. This suggests that specific sequence learning of a complex motor task and its transfer to a new skill occurs independently of sleep. The authors suggest that the non-significant results were due to the transfer task not being goal-based which has been shown to have the best consolidation benefits (Cohen et al., 2005). The explanation here demonstrates the importance of setting up an appropriate transfer test. The taxonomy from chapter two can help future studies consider what the main purpose of the transfer test is.

Additional evidence of neutral transfer for state transfer conditions comes from Paul and colleagues (2020) who examined participants with Parkinson’s disease training either on or off their dopamine replacement medication. Parkinson’s disease is associated with declines in motor function due to a loss of dopaminergic neurons within the basal ganglia which have an impact on motor control and regulating motor learning (Jankovic, 2008). Dopamine replacement medication has been shown to benefit motor performance in Parkinson’s disease patients but has mixed results following a period of no training (i.e., retention), which may be due to difficulties with motor learning in this population (Marinelli et al., 2017; Nackaerts et al., 2016; Nieuwboer et al., 2009; Vanbellingen et al., 2017). In the study by Paul and colleagues (2020), the motor task was a non-dominant functional kidney bean scooping task (into cups task measured by trial time). Participants were randomized to either train with the functional motor task while either “on” or “off” medication. All participants were assessed nine days later “on” medication for a transfer test to a nine-hole peg test and a functional dexterity test. While the group on medication did have better motor performance and retention than the off-medication group, the results of this study reveal that the transfer test to the nine-hole peg test was not significantly different between the two medication conditions. This suggests that the state of being on dopamine replacement medication is able to replace lost dopamine in the degenerating sensorimotor areas of the striatum to help with motor performance and retention, but is not helpful in motor skill transfer or generalizability. The authors note that their transfer test was functionally different from their training task (i.e., reaching vs. dexterity), suggesting that the motor tasks are not similar enough. Here, the use of the taxonomy language from chapter two would have been helpful to label the aim of the transfer test. Technically, there are two elements being transferred, from off-medication to on-medication, and both groups try a peg transfer task. This lack of systematic transfer test organization can lead to inconsistent conclusions.

In the four cases cited above, studies examining muscular fatigue, pain, sleep, and dopamine replacement medication, all found indications of neutral transfer to their respective motor learning transfer tasks (Barnett et al., 1973; Bouffard et al., 2016; Genzel et al., 2012; Paul et al., 2020). This suggests that in most (i.e., four out of seven studies) instances of state transfer studies, motor learning task properties are not helpful in generalizing to another motor task or context. From the limitations seen in the above studies, considerations should include using appropriate measures, uncontaminated training regimes, consideration about the goal of the transfer test, and not confusing retention tests with transfer tests.

4.2.7 State Transfer Taxonomy: Negative Transfer

The one instance of negative transfer in the state transfer category from chapter two is by Movahedi and colleagues (2007) who examined high-arousal compared to low-arousal in physical education students on a basketball free throw task. Participants in the high-arousal condition underwent a progressive use of motivational techniques, including pep talks, verbal exhortation, goal setting, spectators, task importance, evaluation, and rewards. Participants in the low-arousal condition only had their performance scores recorded. The transfer task consisted of the groups switching arousal conditions. The results demonstrate a significant decrease in performance from training in a high-arousal state and transferring to a low-arousal state, and as well for vice versa. This suggests that training under the condition of either a high- or low-arousal level can have detrimental performance when switched to the opposite level of arousal in a basketball free throw task. Therefore, in that experiment, practicing under a state of high arousal created an experience that led to the specificity of practice for the physical education students. It should be noted, however, the authors only examined the arousal transfer from the end of acquisition, not from the start of acquisition. Based on their figure (see Figure 4.1 below), the decrement in performance in retention (Ret) from the arousal switch (As) is worse than their peak acquisition performance and retention (Ret) in their experienced arousal state (Eas) but is still better than their first attempts (Pre).

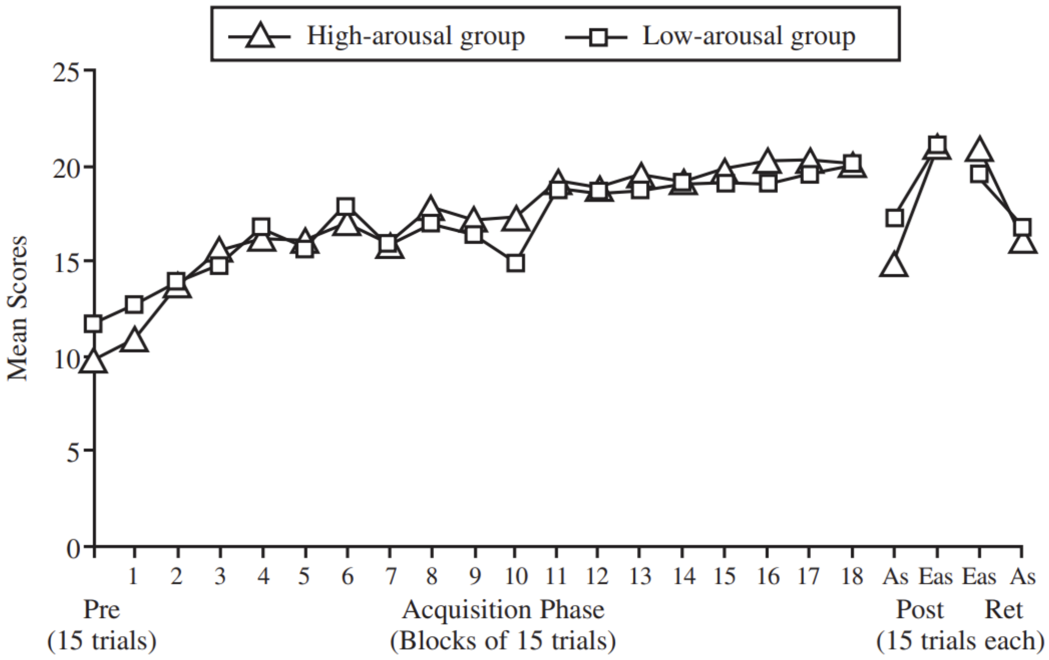


FIGURE 1. Mean performance scores of the experimental groups in pretest (Pre), 18 acquisition sessions, posttest (Post), and retention test (Ret). As = arousal switching (high arousal level for low-arousal group and low arousal level for high-arousal group). Eas = experienced arousal state (high arousal level for high-arousal group and low arousal level for low-arousal group).

Figure 4.1: Results from the only state transfer study with 'negative transfer' results (adapted from Movahedi et al., 2007)

The interpretation is a major limitation of the study and questions remain as to whether the arousal switch actually results in a positive transfer from the start of acquisition. Based on the operational definition from chapter one, to classify as ‘specificity of practice’, the motor skill should demonstrate no generalizability from the previously learned task. From this figure above, there does appear to be motor skill generalizability from the start of acquisition, at the end of the experiment, both arousal switch groups have superior performance from their acquisition of the task at the start of the experiment.

4.2.8 State Transfer Taxonomy: Mixed Results

There was one article cited in chapter two that resulted in mixed results (a mix of positive transfer and neutral transfer) from state transfer. King and colleagues (2020) examined cold versus thermoneutral temperatures on the learning of a grooved pegboard task measured by time. Participants in the cold group immersed their hand in cold water (2°C), while the thermoneutral group immersed their hand in thermoneutral water (34°C). The transfer test involved participants switching to the opposite condition from which they trained. Exposure to cold temperatures during a motor task has been shown to slow nerve conduction velocity (Rutkove, 2001) and impair motor performance (Cheung et al., 2003). Results of the study reveal that accuracy, but not speed, was improved by cold training. This suggests that accuracy improves from training in cold conditions, but the time for completing the task did not differ between groups. The authors addressed limitations with their experimental conditions where they did not keep the hand cool throughout the completion of the entire task, making some of the task being performed at temperatures above the starting cold temperature. This is an important consideration when manipulating any state of a participant to be mindful of the upkeep throughout training.

The above-mentioned articles are the current evidence for state transfer experiments from chapter two. With these articles, the gap of no positive transfer results for state transfer indicates that state transfer may be one of the more susceptible taxonomies to experiencing an outcome other than positive transfer. From chapter two, the theoretical explanation for both neutral transfer and negative transfer is sensorimotor representations. Therefore, it can be suggested that state transfer studies for the most part (aside from half of the one mixed results example) support the sensorimotor representation theory (see chapter one 'Theoretical Perspectives in Specificity of Motor Learning'). The purpose within this investigative framework is to further explore one of the rarer types of negative transfer, state transfer, and to explicitly organize an experiment that should create learning conditions most likely to induce negative transfer. Based on Proteau (2005); Proteau and colleagues (1987, 1992, 1998); Proteau and Isabelle (2002) ideas of specificity of practice, this experiment aims to create a sensorimotor practice context such that when that context is removed and replaced with a different sensorimotor context, significant differences in performance (i.e., real performance decrements in the novel sensorimotor condition) should be observed. Next, we implemented the framework from chapter two as a methodological guide throughout a state transfer experiment.

4.3 Method

4.3.1 Participants

Forty-eight adults aged 18-35 (56.2% female) were recruited from the McMaster University community and the surrounding Hamilton, Ontario area (see Appendix G). Twelve participants were excluded for: not having sufficient physical fatigue washout as determined by the final maximal voluntary contractions (MVCs), and equipment error leaving <80% usable trial data. Thus, thirty-six adults aged 18-35 years (M = 27.3, SD = 3.4) (55.6% female, 91.7% right-handed) were included in this study and were randomly assigned to two distinct groups: a physical fatigue group and a no physical fatigue group.

All participants reported no upper limb impairments (i.e., anything that would infringe on the ability to draw including muscle strains, finger injuries, carpal tunnel syndrome), normal or corrected-to-normal vision (i.e., glasses or contact lenses), no self-reported learning impairments, and no previous experience using a trackpad using the fifth digit (see Appendix H). Prior to testing, participants received a letter of information to outline the types of tasks to be performed, the duration of the sessions, and physical and social risks associated with participating in the experiment (see Appendix I). All participants were naive to the purposes of the experiment. All portions of this study were reviewed and approved by the McMaster University Research Ethics Board (MREB#: 1989).

The sample size calculation used in this study is based on a sequential analysis Pocock alpha spending function. This a-priori Pocock spending function is designed to promote research efficiency by allowing interim looks at 33.3%, 66.7%, and 100%

information rate, with appropriately scaled alphas to correspond with each look. This experiment was taken to the 33.3% spending function to demonstrate, as an investigative framework, a viable methodology intended to fill the gap that was found in the scoping review work, experiment. As such, this experiment serves as an exploratory study designed to implement the checklist in chapter two and was therefore not taken to 100% information rate of data collection. Given the 33.3% information rate, any significance discussed in this experiment will not be at the traditional $p = 0.05$ level of confidence, but rather, the appropriate alpha to determine statistical significance was set to $p = 0.0226$ (see Appendix J).

4.3.2 Procedure

To create a state transfer learning experience using physical fatigue, participants were randomly assigned to either a physical fatigue group or a no-physical fatigue group. Note that the motor task remained the same for both groups. Participants practiced the motor task under the physical fatigue conditions to which they were assigned. Upon completion of this acquisition phase, participants performed two retention tests (immediate and delayed) and a transfer test in which they performed the task under the other fatigue condition (physically fatigued to non-physically fatigued and vice versa). The motor task that both groups completed was a novel wrist flexion and extension task with a focus on using the fifth digit to trace a waveform on a mouse trackpad. The motor task used relevant musculature to the location of the physical fatigue induced and could be quantified with measures of accuracy. The fatiguing protocol used a hand grip dynamometer to elicit physical fatigue in the forearm muscles of the dominant hand that also completed the waveform trackpad motor task. Participants' physical fatigue was measured using objective measures of maximal voluntary contractions (MVCs) as well as subjective measures of perceived physical fatigue. To capture subjective measures of physical fatigue, all participants were asked 'what is your current level pf physical fatigue in your dominant arm on a continuous scale from 0-100 (0 = not at all fatigued, 100 = extremely fatigued)'. This subjective measure was captured at baseline, after MVCs, after each block of trials, after the 30-minute break, and at the end of the experiment and were provided verbally from the participant.

4.3.2.1 Physical Fatigue Group

Using the Camry Electronic Hand Dynamometer, 3 maximal voluntary contractions (MVCs) were assessed on the dominant hand with the elbow supported on the table in front of the participant. This position was to isolate the activation of the forearm muscles congruent with the muscles used for the motor task. Participants were given an opportunity to adjust the grip size on the dynamometer to fit their needs. Once an adjustment was selected, they were instructed to leave the sizing in that position for the rest of the session. Participants were counted in to squeeze the dynamometer as hard as possible until they had reached their self-reported thus subjective maximal effort. The dynamometer was set to display the top score on the screen from each trial. The best of 3 MVCs was used to calculate 60% of their maximal effort. The fatiguing task was to hold 60% MVC until the force dropped below 50% MVC for more than 5 seconds. A similar protocol to Smolander and colleagues (1998) was used where their experiment also had participants hold 60% MVC on a handgrip until failure and found increased measures of physical fatigue (e.g., heart rate and blood pressure) with participants that held the 60% MVC compared to 20% and 40%. Bhambhani and colleagues (2014) also found 60% MVC workloads caused physical fatigue attributed to reduced muscle oxygen availability. Immediately following the physically fatiguing task, participants began Block 1 (20 trials) of the motor task. At the end of the session, three more MVCs were collected.

Physical fatigue was measured using participants' percentage of MVC performance from baseline to end of the day for day one and day two using independent t-tests to compare means. Both standard deviation (SD) and standard error of the mean (SEM) are displayed to provide contextual information towards both a measure of how dispersed the data is in relation to the mean, as well as a measure of how far the mean of the data is likely to fall from the true population mean, respectively. To test that participants in the physical fatigue group were no longer physically fatigued at the end of their day two test, they were required to complete MVCs that were within a $\leq 10\%$ change from their start of day two MVC. Any participants who failed to demonstrate sufficient physical fatigue were excluded.

4.3.2.1.1 MVCs (Maximal Voluntary Contractions)

Outcomes from the physical fatiguing protocol revealed an overall significant decrease $F(1, 34) = 9.17$, $p = 0.005$, $n_p^2 = 0.03$ in the change of the participants' percentage of MVC force performance from the baseline squeeze ($M = 98.54\%$, $SD = 3.92$, $SEM = 0.92$), to the end of day one ($M = 89.25\%$, $SD = 9.26$, $SEM = 2.18$) on the hand grip dynamometer. On day two, after a washout period of rest, the physical fatigue group demonstrated an overall significant decrease *F*(1, 34) = 14.54, $p < 0.001$, $n_p^2 = 0.029$ in MVC performance, while maintaining a squeeze within 10% of their maximal effort from baseline (*M* = 99.56%, *SD* = 1.08, *SEM* = 0.25) to end of day two (*M* = 96.36%, *SD* = 3.04, *SEM* = 0.72). Also on day two, the no-physical fatigue group had an overall significant decrease *F*(1, 34) = 7.03, $p = 0.012$, $n_p^2 = 0.03$ from baseline (*M* = 98.71%, *SD* = 2.67, *SEM* = 0.63) to end of day two (*M* = 95.08%, *SD* = 5.12, *SEM* = 1.21) in MVC performance. (See Figure 4.2)

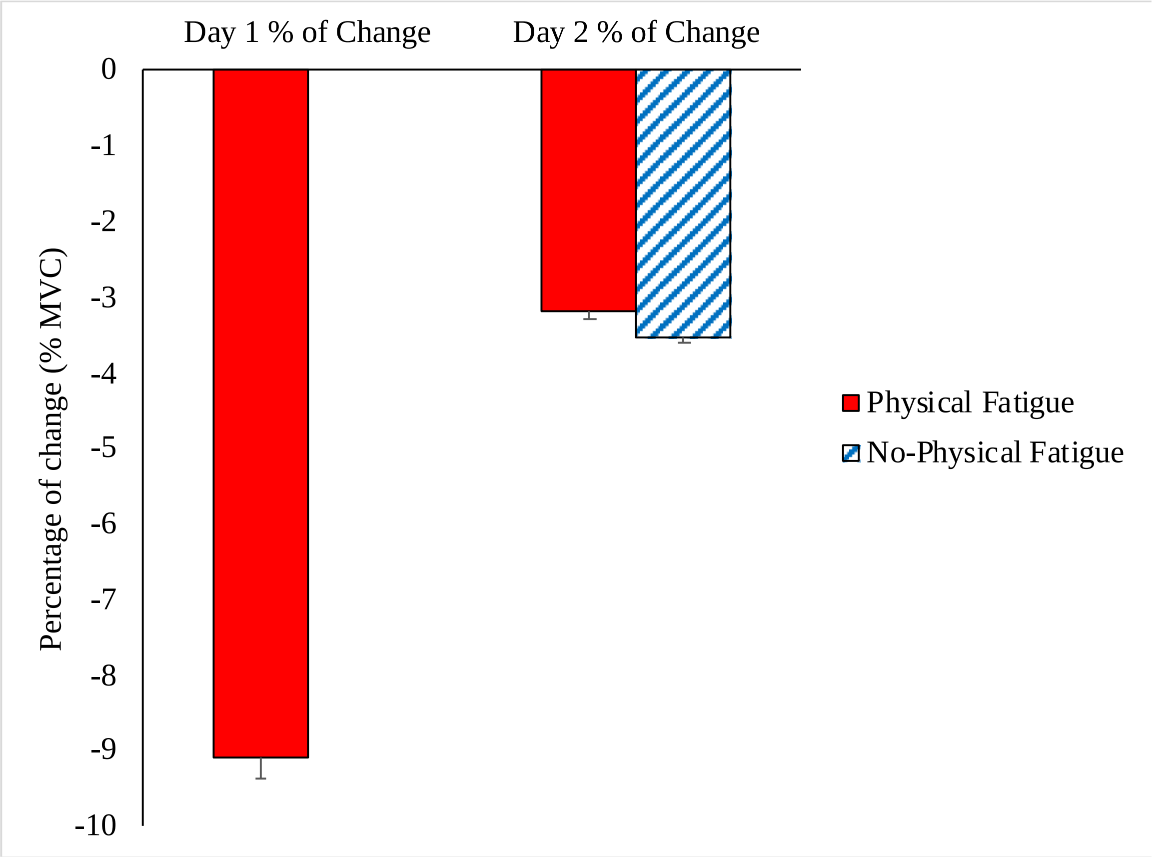


Figure 4.2: Physical fatigue levels indicated by percentage (%) of change from baseline to end of day maximal voluntary contractions (MVCs)

To confirm that each participant in the physical fatigue group had experienced localized physical fatigue, the MVC data from baseline to the end of the test were compared to the 60% MVC holds. The decrease in MVC performance from day one baseline to end of day two for the physical fatigue group can be associated with the protocol eliciting physical fatigue. The four blocks in acquisition are displayed as 'A1, A2, A3, A4', the two immediate retention blocks are displayed as 'I1, I2', the two delayed retention blocks are displayed as 'R1, R2', and the two transfer blocks are displayed as 'T1, T2'.

4.1.1.1.1 60% MVC Physical Fatigue Maintenance

The physical fatigue group performed a hand grip dynamometer hold at 60% MVC for an average of the following durations (in seconds): before A1 (*M* = 55.99, *SD* = 23.00), before A2 (*M* = 49.64, *SD* = 13.89), before A3 (*M* = 44.01, *SD* = 12.22), before A4 (*M* = 39.29, *SD* = 10.82), before I1 (*M* = 37.04, *SD* = 12.37), before I2 (*M* = 33.12, *SD* = 11.38), before R1 (*M* = 45.59, *SD* = 14.81), before R2 (*M* = 42.9, *SD* = 10.51) (See Figure 4.3).

The no-physical fatigue group performed the hand grip dynamometer hold at 60% MVC for an average of the following durations (in seconds): before T1 (*M* = 56.20, *SD* = 21.39), before T2 (*M* = 52.02, *SD* = 12.32) (See Figure 4.3).

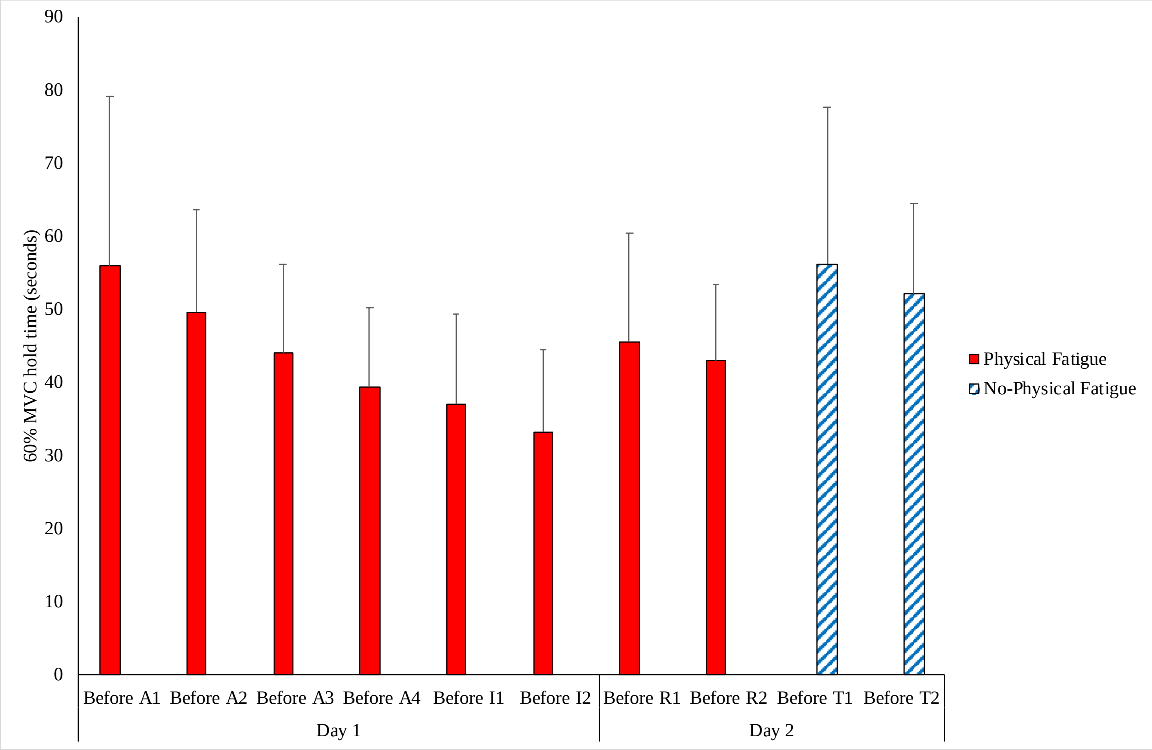


Figure 4.3: Average hold (in seconds) for the Physical Fatigue group and the No-Physical Fatigue group as a function of time

Maintenance of forearm physical fatigue can be seen in the decrease in time to failure from the physical fatigue group baseline hold to the last hold on day one (six total holds on day one). This is to be expected as the 60% hold reoccurred before every 20 trials of the motor task. On day two, two additional holds occurred before each block of 20 retention test trials on the motor task, and likewise for the no-physical fatigue group for their transfer test trials on the motor task.

4.1.1.1.2 Subjective Perceptions of Physical Fatigue

There was a main effect for group, *F*(1, 34) = 8.15, *p* = 0.007, where the physical fatigue group (*M* = 35.60, *SEM* = 1.49) indicated significantly more physical fatigue than the no-physical fatigue group (*M* = 22.85, *SEM* = 1.27) across both days (See Figure 4.4).

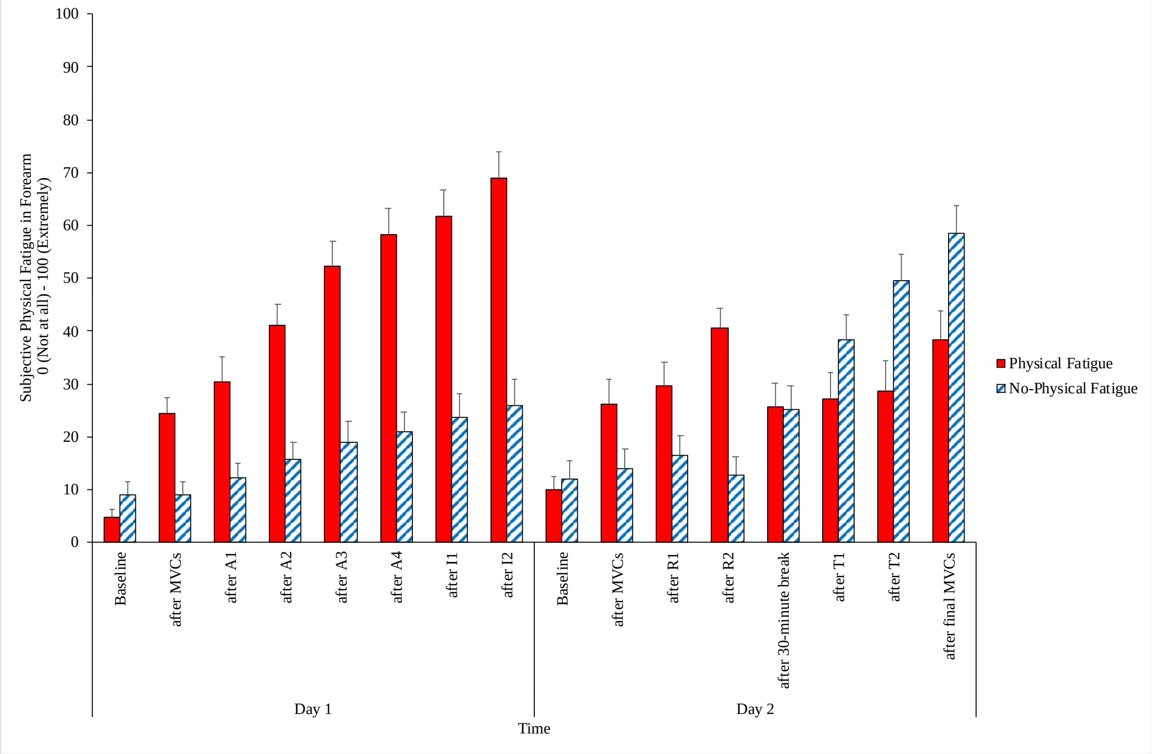


Figure 4.4: Subjective physical fatigue as a function of group and time

The difference between subjective ratings of physical fatigue in the physical fatigue group and the no-physical fatigue group on day one reflects the conditions they trained under as a function of time. On day two, a similar pattern is observed, where subjective perceptions of forearm physical fatigue reflect the group’s condition. After the 30-minute break, the physical fatigue group’s perception of physical fatigue changes as they enter their transfer test without the recurring hand grip holds. While their perceptions of physical fatigue do not return entirely to baseline, this is to be expected with the function of time. On the contrary, the no-physical fatigue group on day two experienced the hand grip holds for the first time, and their subjective feelings of physical fatigue reflect these outcomes as well with greater perceptions of physical fatigue.

4.3.2.2 No-Physical Fatigue Group

Each no-physical fatigue group participant was sex and time matched to a participant in the physical fatigue group. Sex matching was implemented to control for confounding factors of sex differences such as in strength (Hoffman et al., 1979) and in human behaviour (Craig et al., 2004) between groups. Time matching was implemented to control for the no-physical fatigue group participants having a ‘rest’ duration for the same amount of time that the physical fatigue participants held the 60% hold each block. This was to control the overall duration of the study in both groups being 1:1 matched.

4.3.2.3 Motor Task

The following script was used to provide instructions for the motor task, ‘You will be performing a sequence of shape drawing on a program called MatLab. There will be a green “Run” button at the top of the screen, and that is the only thing that you have to click to start each round. Once you click “Run”, a window will appear with a shape on it. It will only appear briefly but take that moment to absorb what the shape looks like. You will use your index finger to get your cursor to the starting position at the top of the shape. The shape will disappear, and you will have a grey screen. With this grey screen, and using your memory, recreate that shape to the best of your ability. You can use your index finger to get your cursor to the correct starting position, however, the actual drawing of the shape will happen with your pinky finger. You will have your hand in a handshake position, with your thumb up, and you will be using your pinky finger's edge to draw out the shape (see Figure 4.5). You may slightly tilt your hand to ensure proper pinky finger pad contact on the trackpad. With your non-dominant hand, once you are done drawing, you will give the left mousepad button on the laptop a click. You will then see feedback on what the goal was, overlapped with what you drew. Work on getting that trace to align as closely as possible with the goal line. Shapes will occur in blocks of 20, after you review your feedback, get ready for the next shape to appear.'

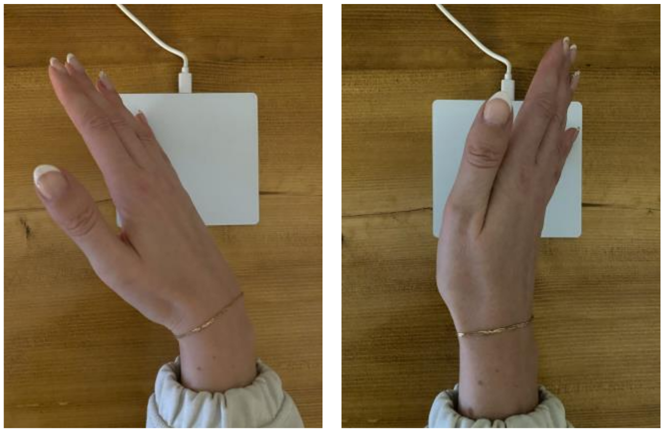


Figure 4.5: Representation of the motor task using the mouse trackpad. The participants' hand were to be in a 'handshake' position, and they were instructed to use the pad of their fifth digit to draw on the trackpad using primarily wrist flexion and extension movements.

4.3.3 Instrumentation

Due to the coronavirus disease 2019 (COVID-19) pandemic, all the equipment described below was designed to be a portable package that was dropped off and picked up from participants' homes. Included in the package was: a Toshiba Ultrabook Laptop, laptop charger, Camry Electronic Hand Dynamometer, HAVIT TP050-S Trackpad USB Touch Pad, set-up instructions, and a participant reimbursement receipt (see Appendices K and L). The Toshiba Ultrabook Laptop runs on an Intel® Core™ i3-2367M CPU at 1.40GHz processor with a 64-bit operating system running Windows 10 Education version 20H2 with a 1366 x 768 (recommended) display resolution. The only applications on the laptop desktop were MATLAB, Zoom, and the ‘Our Planet’ documentary video. The HAVIT Trackpad mouse provides data collection at 100Hz, or cursor location every 10ms in pixels. Upon delivery of the portable package, participants were told to follow the set-up instructions sheet a few minutes before their scheduled testing time. The set-up instructions contained laptop power on, charger plug-in, trackpad plug-in, home Wi-Fi set up, and Zoom log-in and password information (see Appendix K).

4.3.4 Procedure Day One

4.3.4.1 Acquisition

Once participants, regardless of physical fatigue condition, were logged into the Zoom call on the delivered laptop with the researcher, the main points from the Letter of Information were described and discussed where necessary, a checklist that equipment was properly set up was confirmed, and the shape drawing task was explained in detail with time for any questions about the task. The baseline level of subjective physical fatigue was obtained by asking ‘How physically fatigued does your dominant forearm feel on a continuous scale from 1-100?’. This subjective physical fatigue was reassessed at the end of each block throughout the experiment. The acquisition phase included 4 blocks of 20 shape drawing trials, totalling 80 trials. In between each block, depending on which group participants were randomized, they either underwent a bout of forearm physical fatigue or rested by watching an emotionally neutral documentary ‘Our Planet’ (*Our Planet by Alastair Fothergill and Keith Scholey with Fred Pearce, Foreword by David Attenborough*, 2019).

A trial consisted of seeing a waveform in one of four random sinusoidal-style shapes (see Figure 4.6). The same random order of shapes occurred for every participant. The waveform would appear for 3-5 seconds with a random fore period to reduce anticipation and routine movements. Once the waveform window disappeared, the participant was presented with a blank window in place of where the waveform window was on the screen. Participants then had to recreate that waveform to the best of their capabilities using their fifth digit. Once the participant completed their trace, they clicked the left mousepad button and a feedback window appeared with their trace overlapped with the original target trace. This visual waveform feedback was provided after every trial in acquisition for both groups.

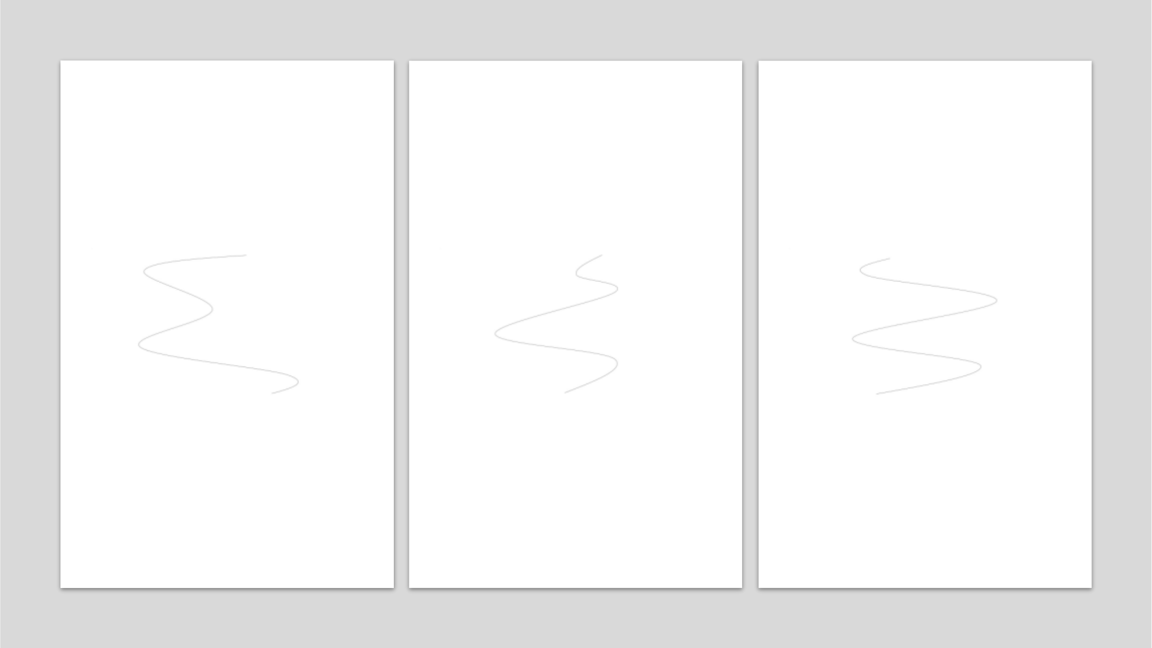


Figure 4.6: Sinusoidal waveform images, presented in random order, that participants would see on the screen in front of them.

4.3.4.2 Immediate Retention

An immediate retention test occurred directly after the last trial of acquisition and consisted of two blocks of 20 trials, totalling 40 trials. Unlike during the acquisition phase of the experiment, these trials contained no visual feedback of participants seeing their trace overlayed with the goal trace. Moving forward, this will be termed ‘no waveform feedback’. This distinction is made to discern from ‘no feedback’ or ‘no visual feedback’ as other sources of sensory and visual information are still available in this study. Participants in the physical fatigue group had a physical fatigue session before the motor task, and participants in the no-physical fatigue group had a time-matched rest before the motor task.

4.3.5 Procedure Day Two

4.3.5.1 Delayed Retention

On day two, approximately 24 hours (*M* = 23.48 ± 1.82) after the acquisition phase, a delayed retention test occurred. To re-establish that sensorimotor physical fatigue in retention, participants in the physical fatigue group underwent 3 new MVC establishment trials and repeated the process of holding 60% MVC prior to entering each block of shape drawing. These blocks were the same as the immediate retention test where no feedback was provided after each trial.

4.3.5.2 Transfer

On day two, 30-minutes after the delayed retention test, a transfer test was administered. It is important to be clear here that the waveform tracing motor task remained the same. The element that is being transferred is the physical fatigue condition wherein participants switched from the physical fatigue condition under which they practiced the task to the novel fatigue state. For example, if a participant was in the physical fatigue group, (i.e., practiced the task with forearm physical fatigue throughout the acquisition and performed also under physical fatigue for the immediate retention test and delayed retention test), then their transfer test was without physical fatigue. To ‘washout’ forearm physical fatigue, a 30-minute rest occurred where all participants watched an emotion-neutral documentary ‘Our Planet’. Participants in the physical fatigue group would then begin the motor task with their forearm feeling as ‘fatigue-free’ as possible. Participants in the no-physical fatigue group would experience the physical fatigue protocol for the first time prior to entering the motor task in the transfer test.

4.3.6 Dependent Variables

The dependent variables of interest in this experiment are root mean square error (RMSE) in pixels and movement time (MT) in ms. These measurements are common to novel tracing-style tasks in the motor learning literature (e.g., star tracing) to provide an optimal measure of skill on the task (Drowatzky, 1969). Measurements of RMSE and MT provide spatial accuracy and timing performance respectively. Taken together, RMSE and MT provide a clear and full picture of the participant’s performance on this motor task. Similar to findings by Drowatzky (1969), these spatial and timing measures should be considered which this study examined as correlations between RMSE and MT. In the study of motor learning tasks, a variety of measures have been employed to assess accuracy, including absolute error and autocorrelations, among others. However, this study specifically utilizes Root Mean Square Error (RMSE) as the measure of choice. The preference for RMSE is based on its widespread application in research related to waveform analysis and continuous tracking of novel motor tasks, as evidenced by studies such as those by Proteau et al. (1998) and Boutin et al. (2012a, 2012b). Within the framework of this experiment, RMSE is calculated for each trial by first summing the squared discrepancies between the observed performances and the target values. This sum is then divided by the total number of observations, and the square root of this quotient is taken. By doing so, RMSE quantitatively evaluates the variance between the participant's actual movements and the intended target path on a point-by-point basis, offering a precise measure of performance accuracy. To normalize the comparisons, the participant’s waveform trace and the target trace were sampled at 100Hz or 10ms and matched at peak-to-peak amplitudes. MT was calculated from the start of the participant's waveform drawing until the end of the drawing, and their left mouse button clicked to indicate they were done drawing. Every 20 trials were averaged together to form one block per participant. There were a total of 80 acquisition trials (four blocks), 40 immediate retention trials (two blocks), 40 delayed retention trials (two blocks), and 40 transfer test trials (two blocks). In situations where there were no significant differences, data are also displayed in a collapsed version, where all test blocks are presented together for conciseness (e.g., acquisition blocks ‘A1, A2, A3, A4’ are collapsed together as ‘acquisition’).

4.3.7 Statistical Analyses

As noted in the introduction to this thesis, our final sample size of 36 participants is commensurate the sample sizes of the bulk of the studies that comprise the specificity of learning literature. For this reason, we completed statistical analyses on our data to serve as a point of comparison with those other studies.

The data obtained from the dependent variables during acquisition were analyzed using a 2 (group) x 4 (block) mixed analysis of variance (ANOVA) with repeated measures on the second factor. To measure immediate retention vs. delayed retention, a 2 (group) x 2 (day) x 2 (block) mixed ANOVA with repeated measures on the last two factors was conducted. To measure retention and transfer, a 2 (group) x 2 (test type) x 2 (block) mixed ANOVA with repeated measures on the last two factors was conducted. The primary analysis examined the first two blocks of early acquisition (EA) to the two blocks of transfer in a 2 (group) x 2 (test type) x 2 (block) mixed ANOVA with repeated measures on the last two factors. The main effects and interaction analyses were used to test for significant differences between the group and test using a Greenhouse Geisser correction for sphericity. Effects were further decomposed using Tukey's honestly significant difference (HSD) test for post-hoc analyses. Partial eta squared (n_p^2) was used to measure the effect size for the ANOVAs. Pearson *r* correlations were used as secondary analyses to provide further contextual information into the speed and accuracy measures together. All analyses were completed using the SPSS Statistics Software Package (Version 28.0, IBM).

4.4 Results

For the purposes of this thesis, all analyses are reported regardless of the level of statistical significance.

4.4.1 Movement Time (in milliseconds) Across all blocks (not collapsed)

There was no main effect for group, F (1, 34) = 4.470, p=0.042 (Figure 4.7).

There was a main effect for block, F (9, 306) = 3.703, $p < 0.001$, $\eta_p^2 = 0.098$. Participants from A1 (*M*= 5258.49, *SD*= 2187.43) exhibited significantly shorter MTs than in A2 (*M*= 5683.91, *SD*= 2566.59), A3 (*M*= 5996.58, *SD*= 2546.99), A4 (*M*= 6163.84, *SD*= 2697.82), I1 (*M*= 5941.19, *SD*= 2654.30), and R2 (*M*= 5819.66, *SD*= 2438.42). Participants in A2 exhibited significantly shorter MTs than A3 and A4. Participants in A3 exhibited significantly shorter MTs than in R1 (*M*= 5568.39, *SD*= 2084.95) and T2 (*M*= 5614.39, *SD*= 2529.30). Participants in A4 exhibited significantly longer MTs than I1, I2 (*M*= 5754.24, *SD*= 2465.28), R1, T1 (*M*= 5705.33, *SD*= 2312.91), and T2. Participants in I1 exhibited significantly longer MTs than I2, R1, and T2. Participants in R2 exhibited significantly longer MTs than T2 (Figure 4.8).

There was no group by block interaction, *F* (9, 306) = 0.275, *p*=0.981 (Figure 4.9).

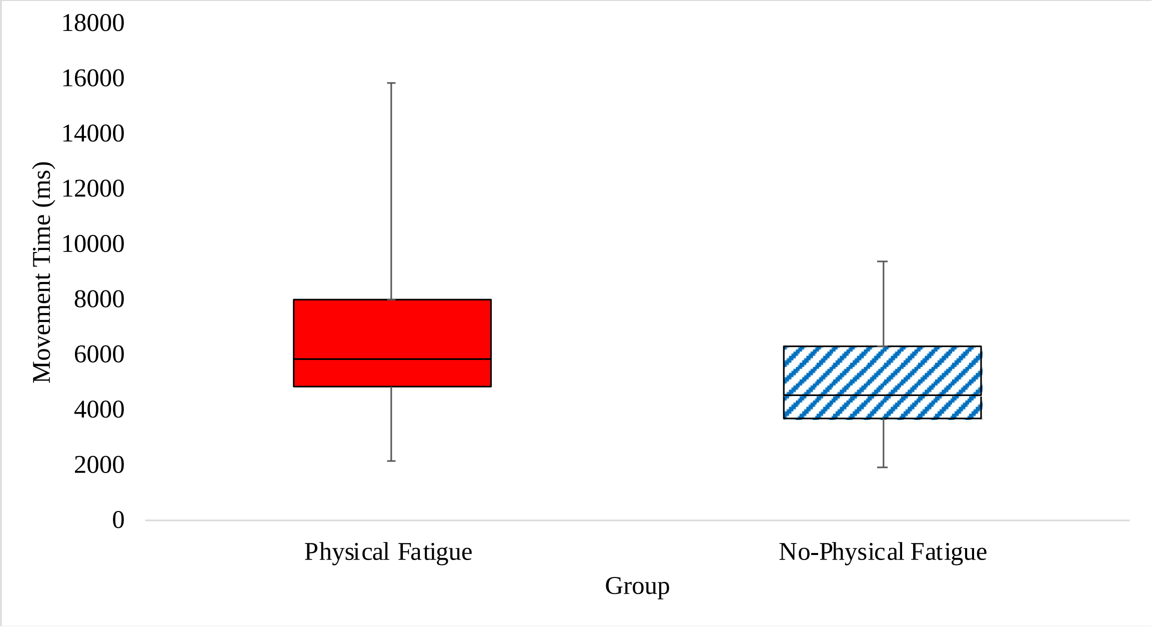


Figure 4.7: Movement time in milliseconds as a function of group

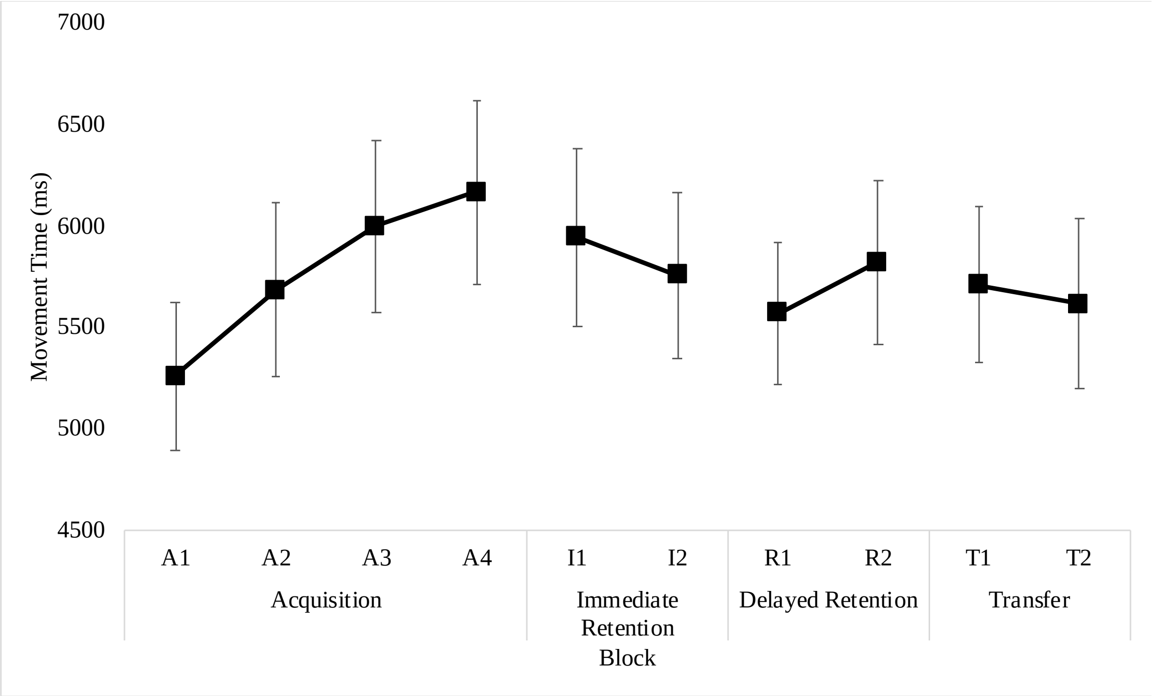


Figure 4.8: Movement time in milliseconds as a function of block

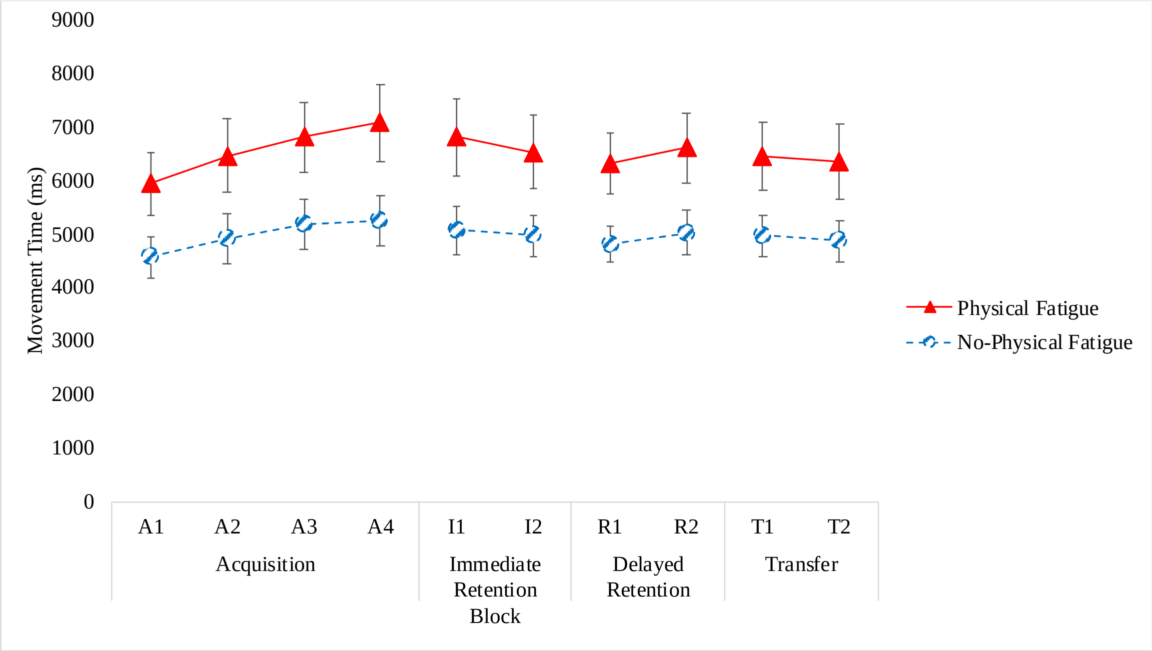


Figure 4.9: Movement time in milliseconds as a function of group and block

4.4.1.1 Collapsed blocks (EA, IR, DR, T) Movement Time (in milliseconds)

There was no main effect for test, *F* (3, 102) = 1.378, *p*= 0.254 (Figure 4.10).

There was no group by test interaction, *F* (3, 102) = 0.109, *p* = 0.954 (Figure 4.11).

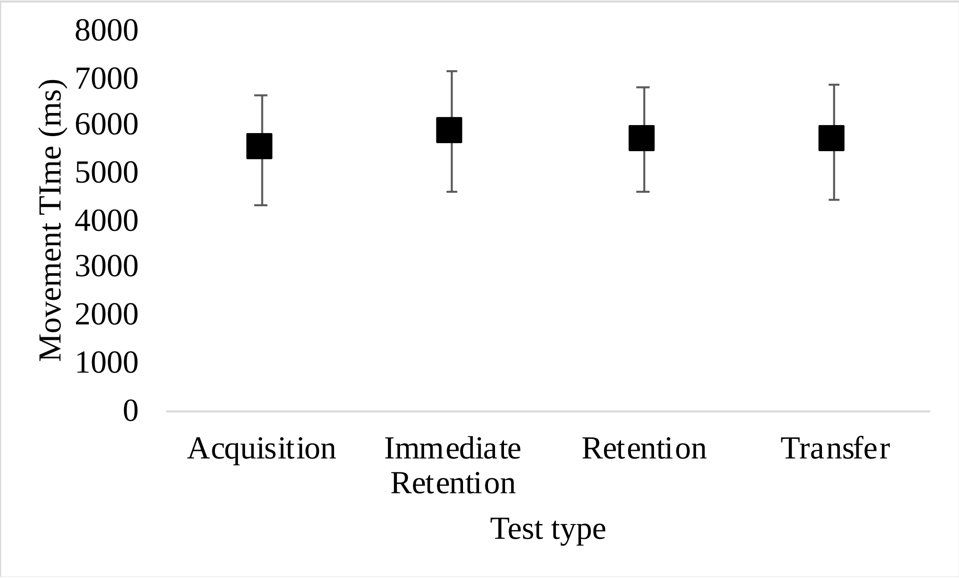


Figure 4.10: Movement time in milliseconds as a function of collapsed blocks (test type)

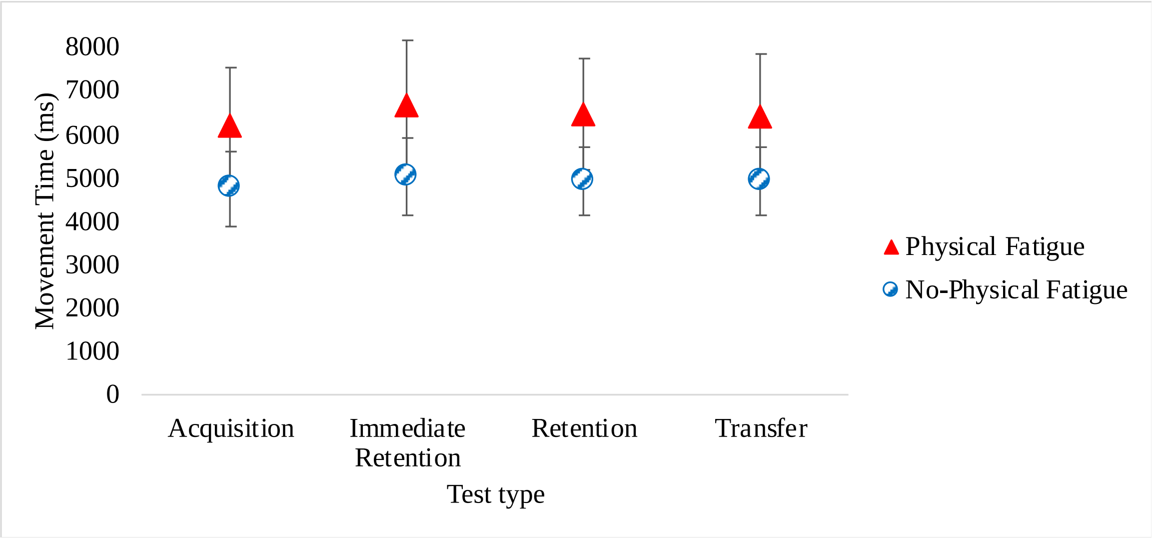


Figure 4.11: Movement time in milliseconds as a function of group and collapsed blocks (test type)

4.4.2 RMSE (Root Mean Square Error) Across all blocks (not collapsed)

There was no main effect for group, *F* (1, 34) = 0.014, *p* = 0.907 (Figure 4.12).

There was a main effect for block, *F* (9, 306) = 5.691, *p*<0.001, $\eta_p^2 = 0.143$ (Figure 4.13). Participants in A1 (*M*= 58.39, *SD*= 8.98) were significantly less accurate than A2 (*M*= 54.85, *SD*= 7.76), A3 (*M*= 54.90, *SD*= 8.72), A4 (*M*= 52.02, *SD*= 8.65), I1 (*M*= 49.25, *SD*= 9.58), I2 (*M*= 51.26, *SD*= 10.80), R1 (*M*= 52.08, *SD*= 9.17), R2 (*M*= 53.63, *SD*= 11.04), T1 (*M*= 52.56, *SD*= 10.38), T2 (*M*= 52.00, *SD*= 11.11). Participants in A2 were significantly less accurate than A4, I1, and I2. Participants in A3 were significantly less accurate than A4, I1, I2, and R1. Participants in A4 were significantly less accurate than I1. Participants in I1 were significantly more accurate than I2, R1, R2, and T1 (Figure 4.13).

There was not a group by block interaction, *F* (9, 306) = 0.649, *p*= 0.755 (see Figure 4.14).

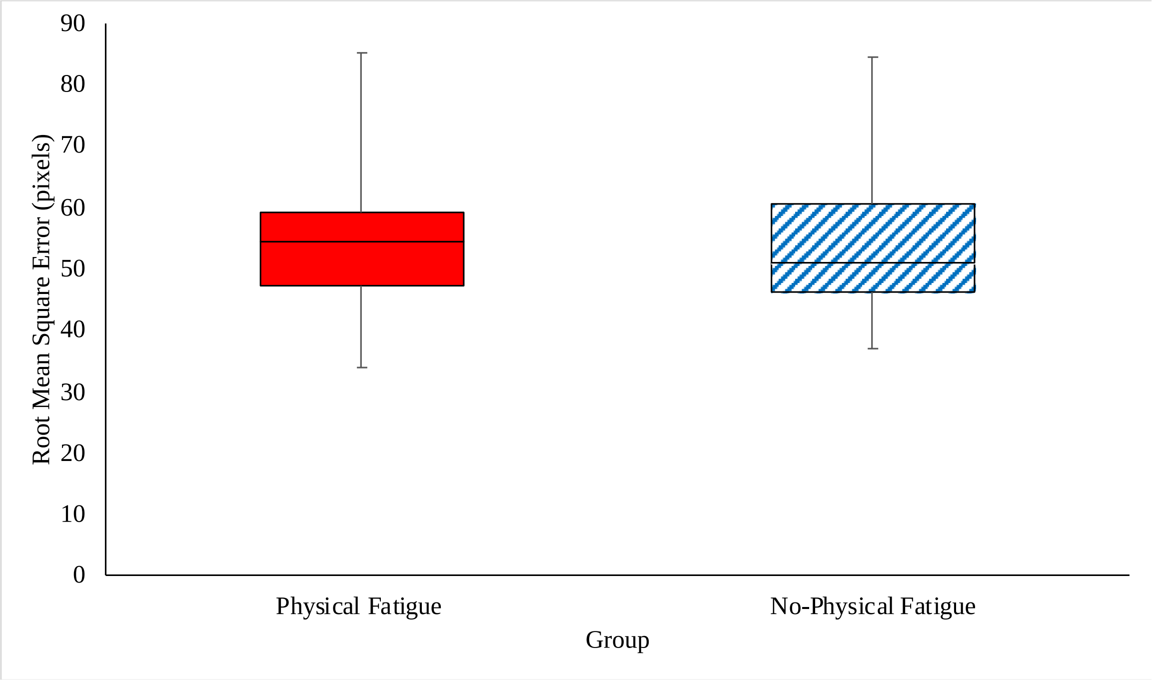


Figure 4.12: Root mean square error in pixels as a function of group

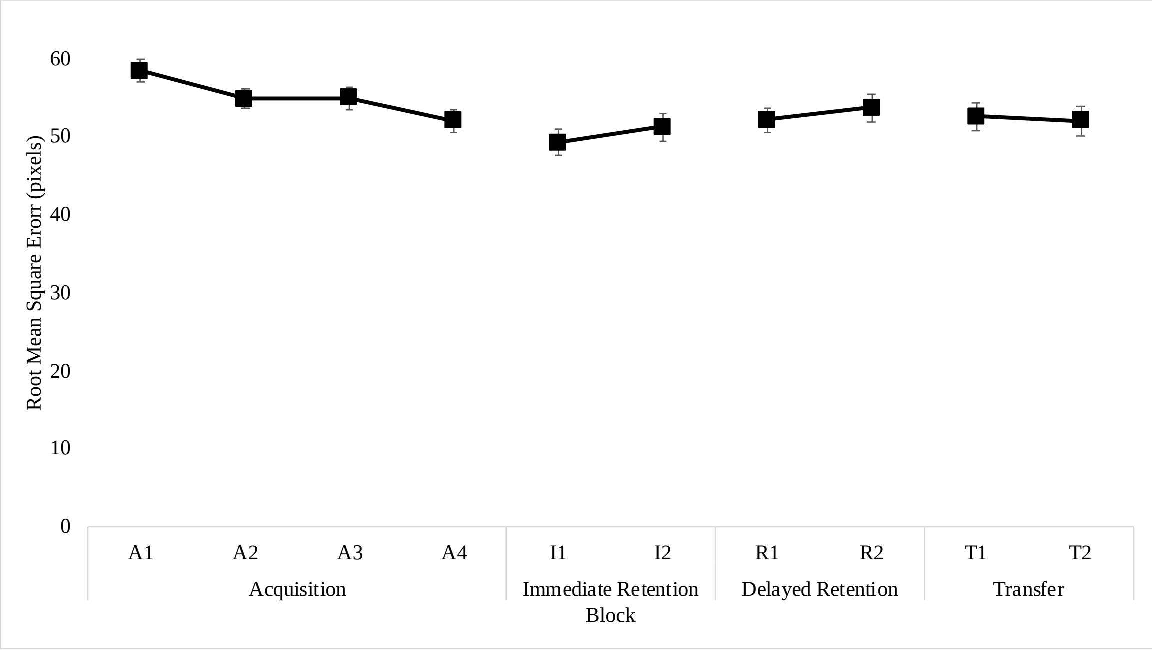


Figure 4.13: Root mean square error in pixels as a function of block

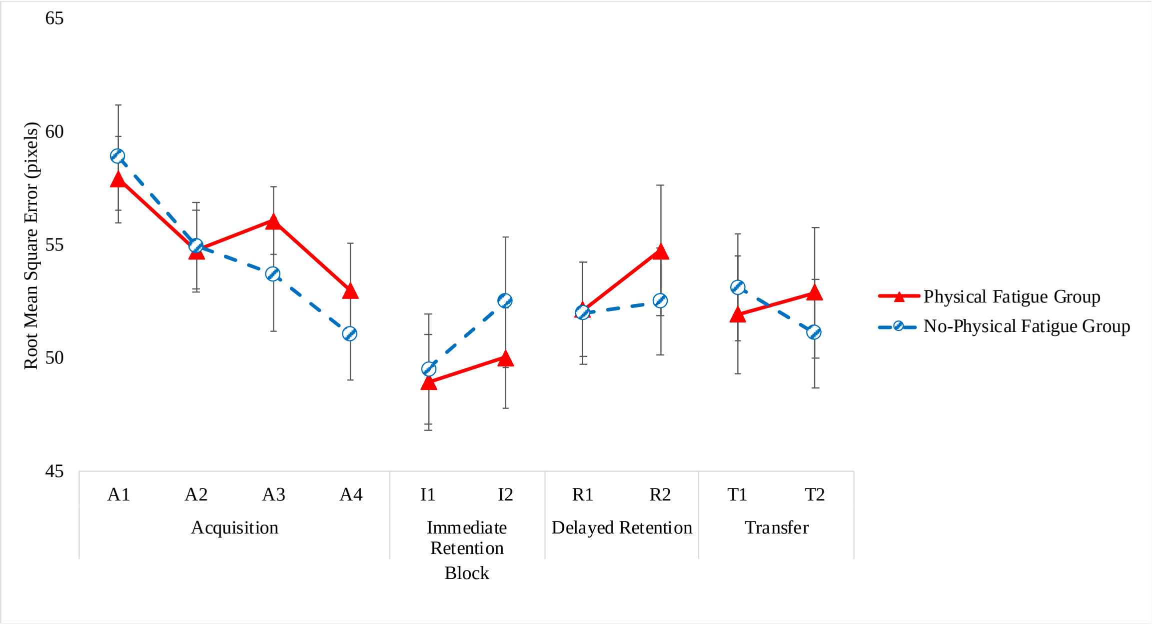


Figure 4.14: Resultant root mean square error in pixels as a function of group and block

4.4.2.1 RMSE (Root Mean Square Error) Collapsed blocks (EA, IR, DR, T)

There was a main effect for test, *F* (3, 102) = 7.535, *p*<0.001, $\eta_p^2 = 0.181$. Participants in acquisition (*M*= 56.62, *SD*= 7.73) were significantly less accurate than immediate retention (*M*= 50.25, *SD*= 9.85), retention (*M*= 52.86, *SD*= 9.66), and transfer (*M*= 52.28, *SD*= 10.23). Participants in immediate retention were significantly more accurate than retention (see Figure 4.15).

There was no group by test interaction, *F* (3, 102) = 0.373, *p* = 0.773 (see Figure 4.16).

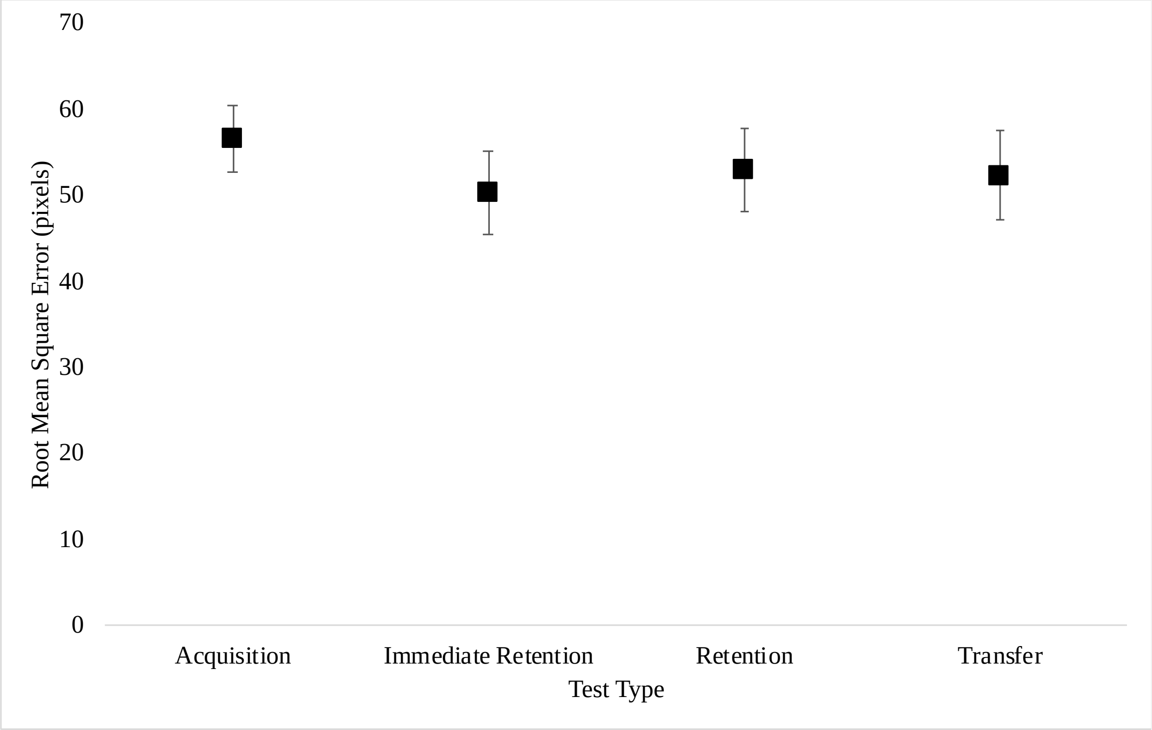


Figure 4.15: Root mean square error in pixels as a function of blocks collapsed (test type)

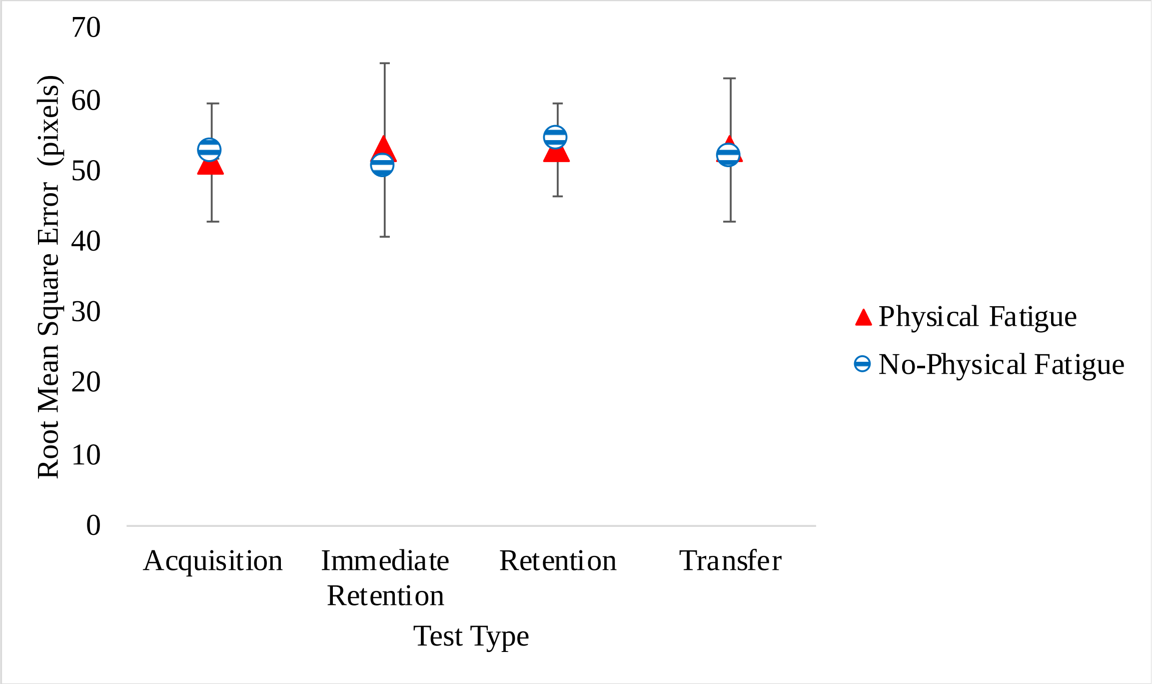


Figure 4.16: Root mean square error in pixels as a function of group and blocks collapsed (test type)

4.4.3 Correlation

A Pearson Correlation analysis examined the relationship between RMSE and MT. The Pearson *r* correlation significance at the $p < 0.02$ level required an *r* of at least 0.542. The RMSE and MT relationship for the physical fatigue group during acquisition was not significant at $r = 0.22$ (see Figure 4.17). The relationship for the no-physical fatigue group during acquisition was not significant at $r = -0.29$ (see Figure 4.18). The relationship for the physical fatigue group during immediate retention was not significant at $r = 0.21$ (see Figure 4.19). The relationship for the no-physical fatigue group during immediate retention was not significant at $r = -0.43$ (see Figure 4.20). The relationship for the physical fatigue group during delayed retention was not significant at $r = -0.30$ (see Figure 4.21). The relationship for the no-physical fatigue group during delayed retention was not significant at $r = -0.52$ (see Figure 4.22). The relationship for the physical fatigue group during transfer was not significant at $r = -0.30$ (see Figure 4.23). The relationship for the no-physical fatigue group during transfer was not significant at $r = -0.47$ (see Figure 4.24).

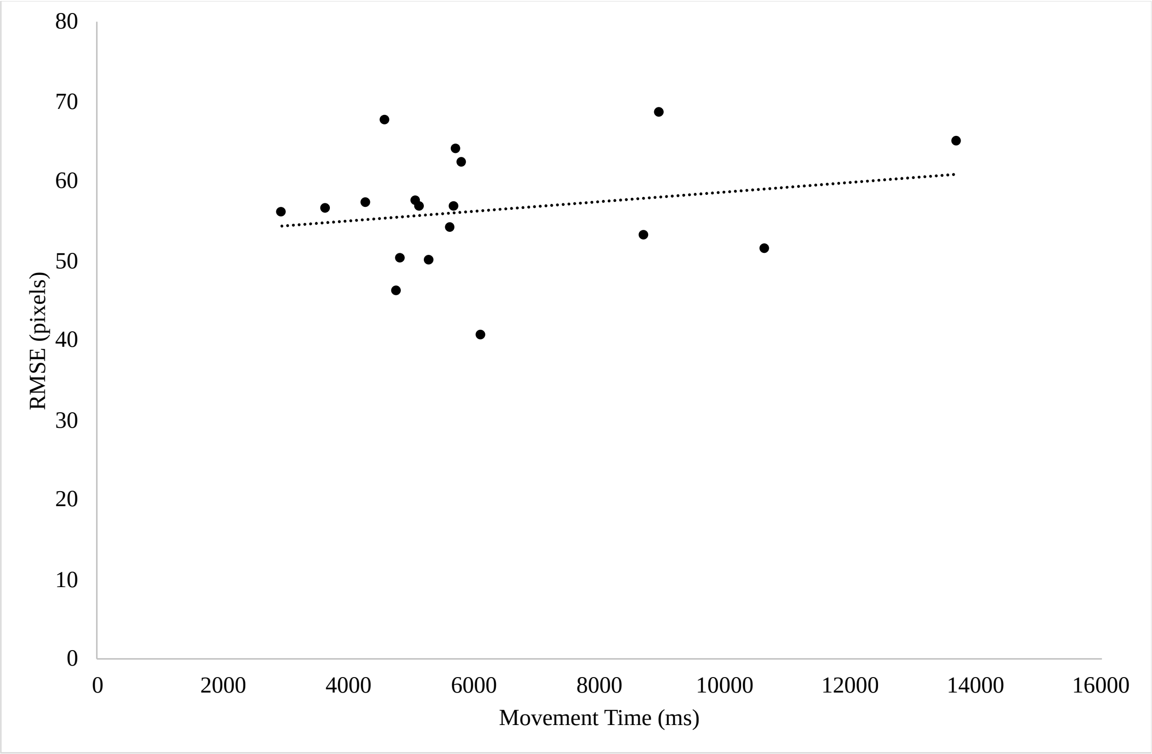


Figure 4.17: Pearson r correlation between movement time in milliseconds and root mean square error in pixels during acquisition for the physical fatigue group

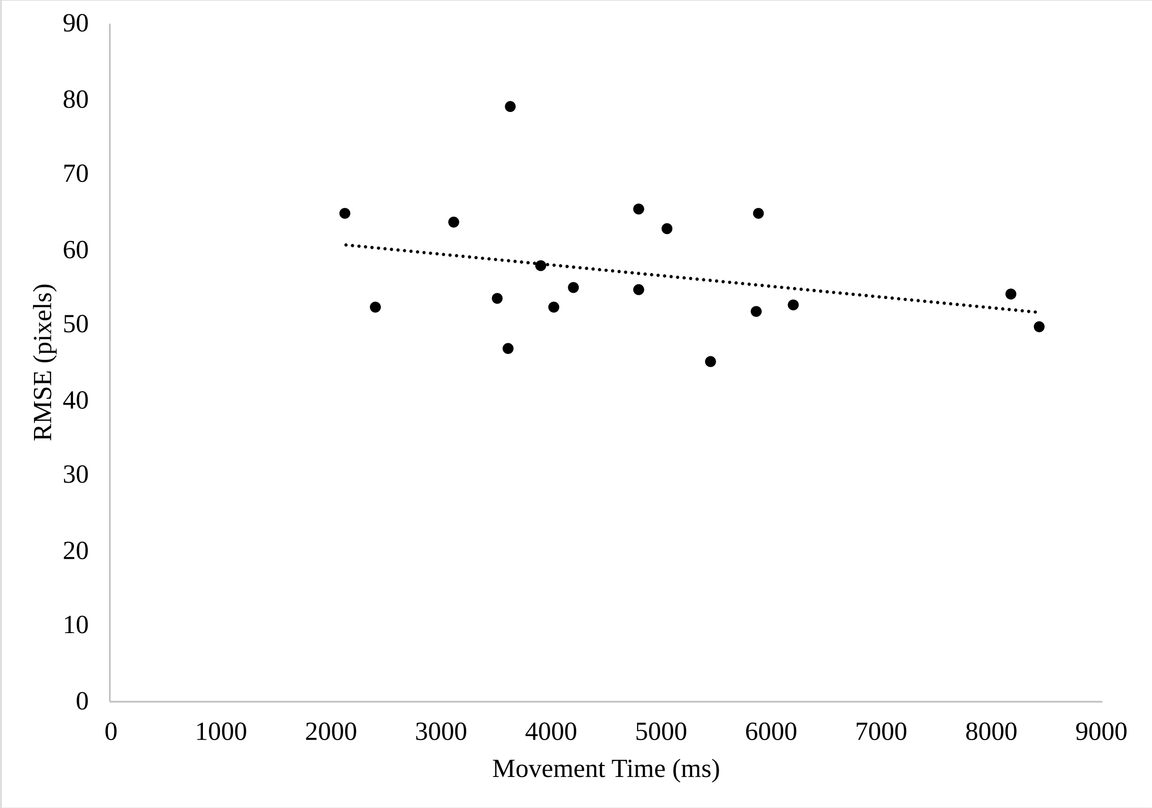


Figure 4.18: Pearson r correlation between movement time in milliseconds and root mean square error in pixels during acquisition for the no-physical fatigue group

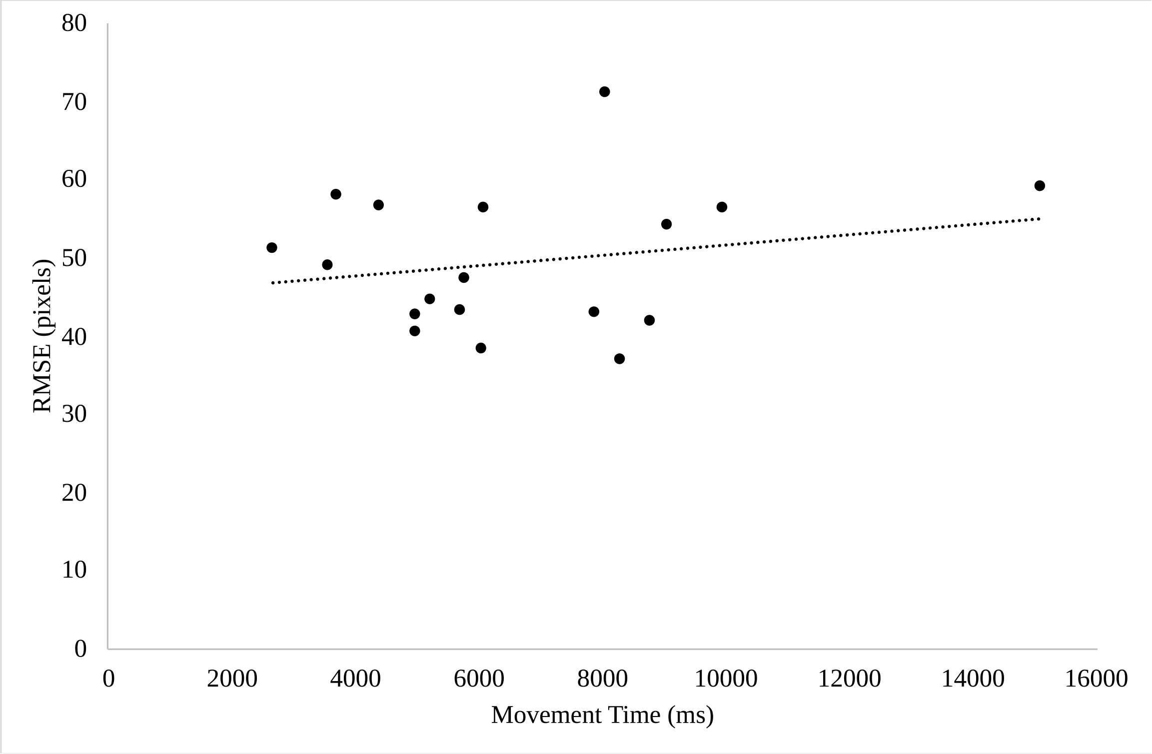


Figure 4.19: Pearson r correlation between movement time in milliseconds and root mean square error in pixels during immediate retention for the physical fatigue group

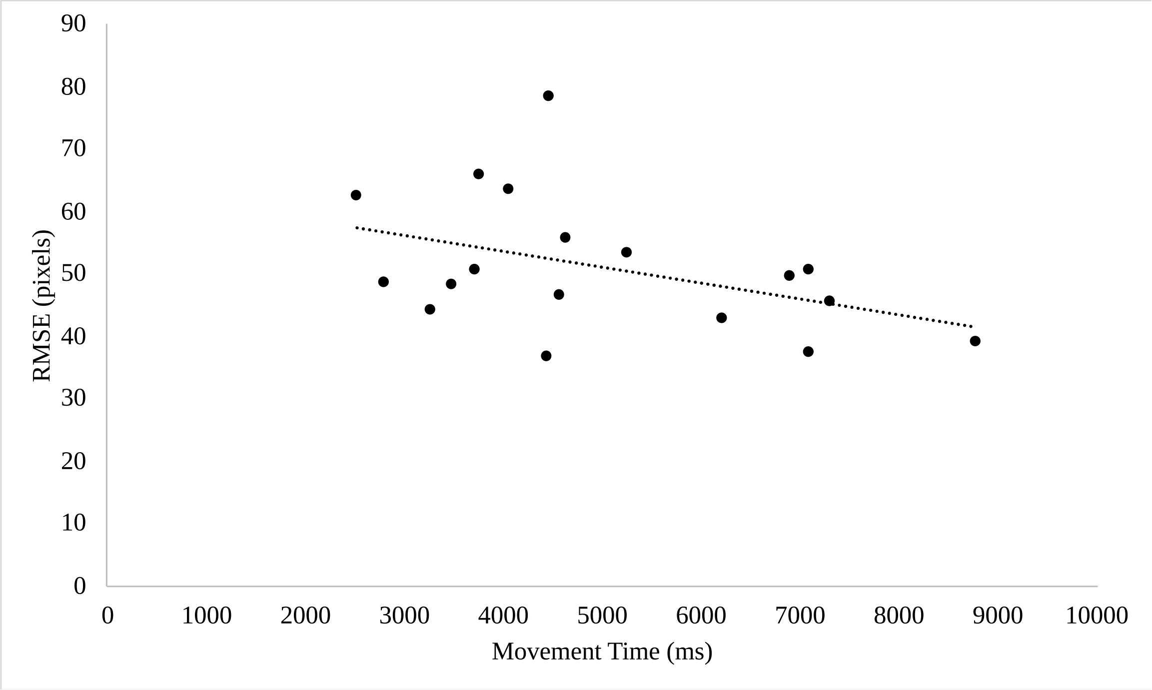


Figure 4.20: Pearson r correlation between movement time in milliseconds and root mean square error in pixels during immediate retention for the no-physical fatigue group

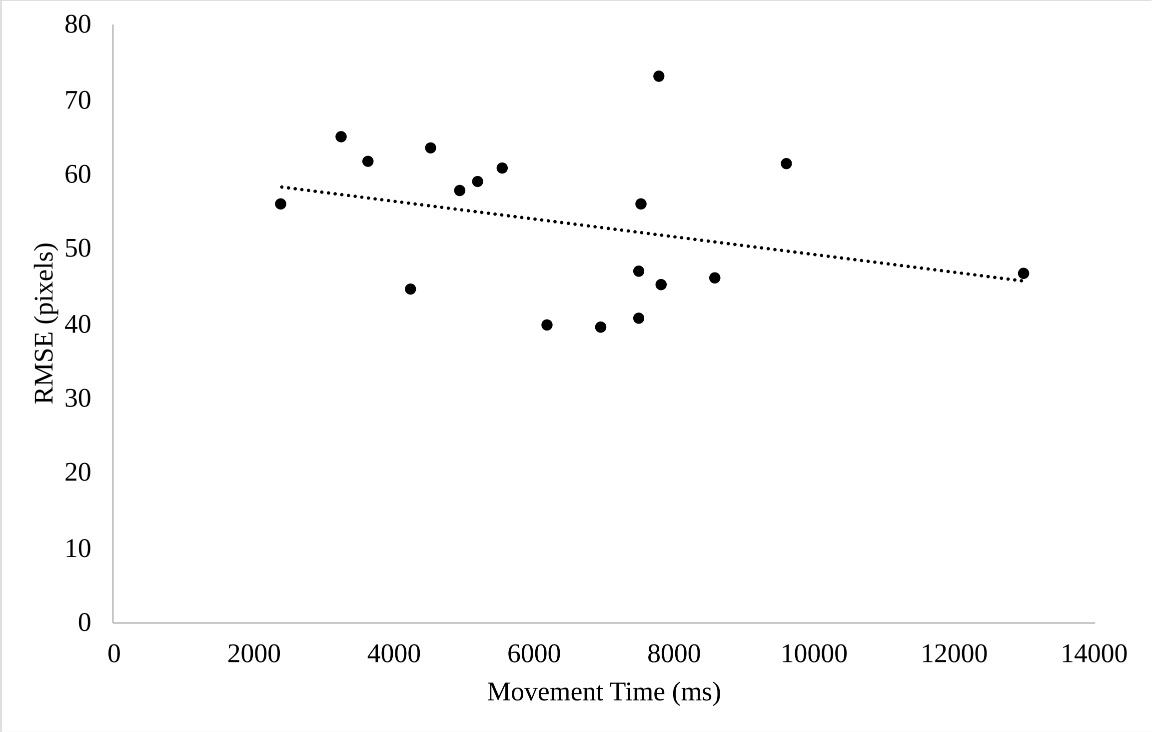


Figure 4.21: Pearson r correlation between movement time in milliseconds and root mean square error in pixels during delayed retention for the physical fatigue group

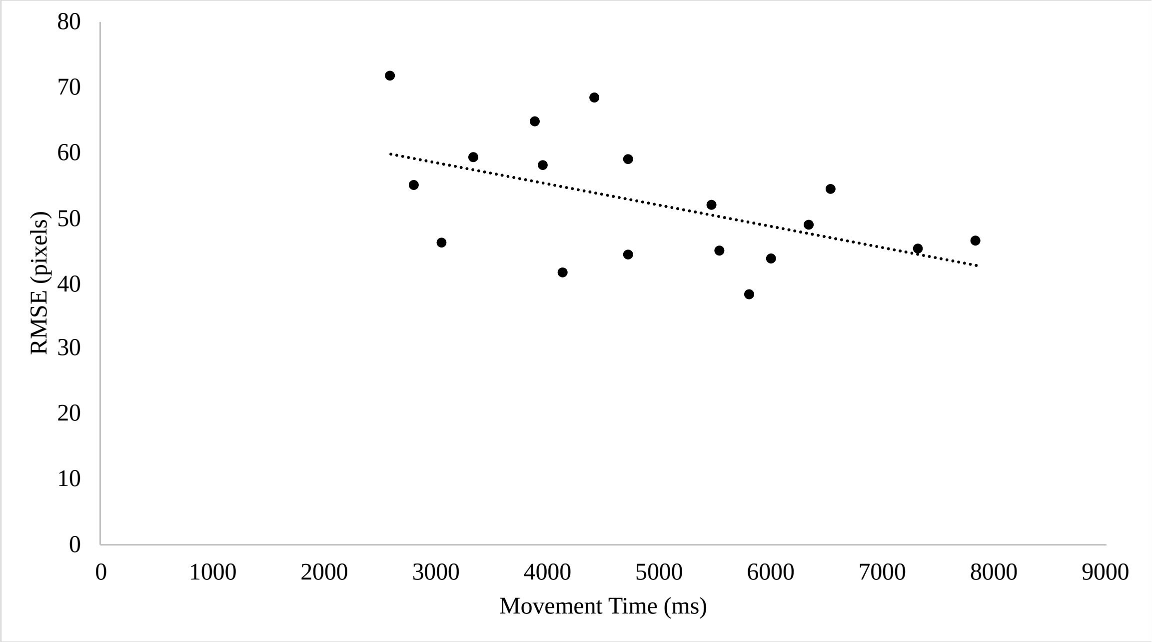


Figure 4.22: Pearson r correlation between movement time in milliseconds and root mean square error in pixels during delayed retention for the no-physical fatigue group

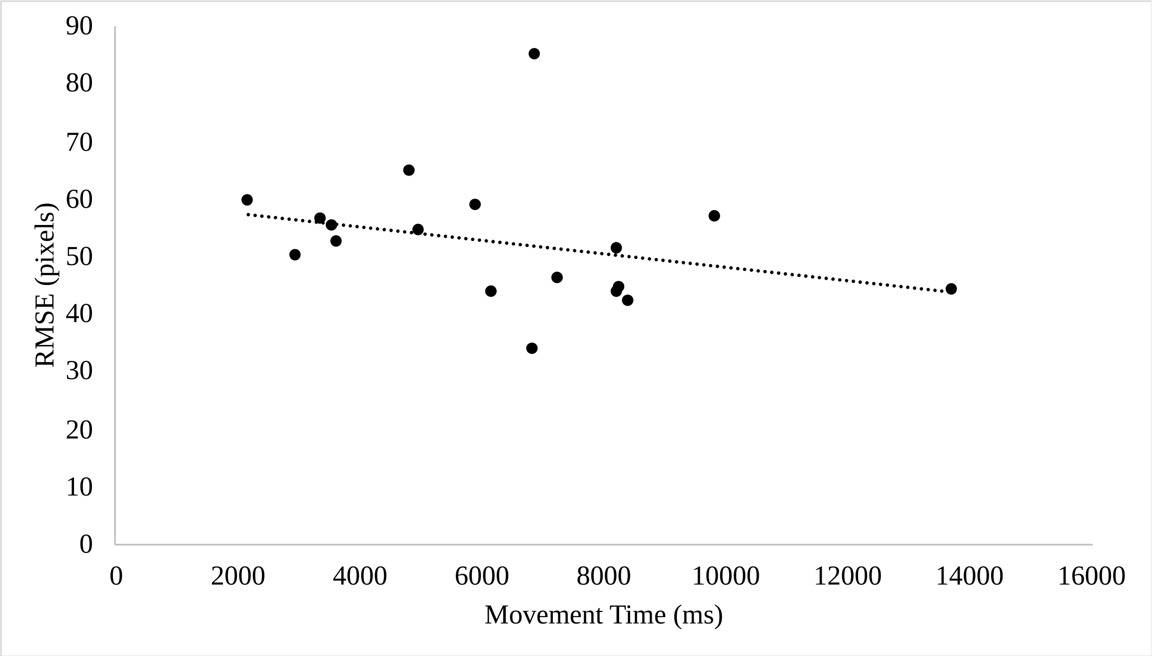


Figure 4.23: Pearson r correlation between movement time in milliseconds and root mean square error in pixels during transfer for the physical fatigue group

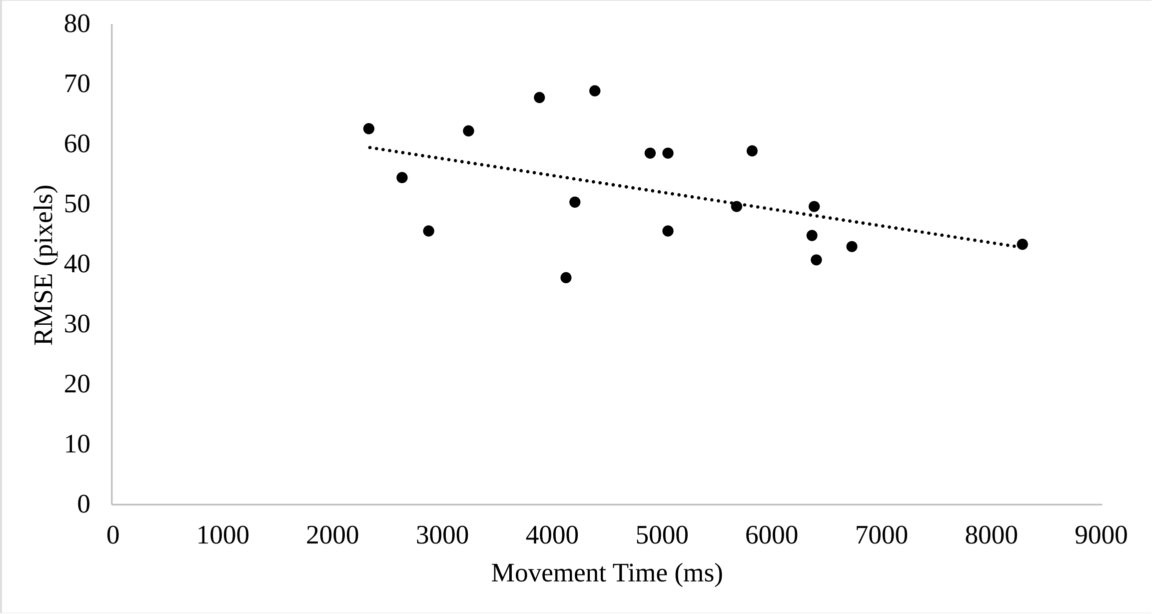


Figure 4.24: Pearson r correlation between movement time in milliseconds and root mean square error in pixels during transfer for the no-physical fatigue group

4.5 Discussion

The purpose of this chapter is to implement the checklist outlined in chapter two. To fully interpret the impact of the checklist, the preliminary analyses of the experimental work is discussed. Previous studies evaluating state transfer report inconsistent results with outcomes of neutral transfer (Barnett et al., 1973; Bouffard et al., 2016; Genzel et al., 2012; Paul et al., 2020), negative transfer (Movahedi et al., 2007), and mixed results (a mixture of positive and neutral transfer) (King et al., 2020). The results of this state transfer framework hypothesized to achieve negative transfer, resulted in neutral transfer. From when participants initially performed the motor task, to their transfer test performing the task under a different physical fatigue condition, there was no change in their motor performance in terms of neither speed nor accuracy. These findings are consistent with the other neutral transfer studies from this category (Barnett et al., 1973; Bouffard et al., 2016; Genzel et al., 2012; Paul et al., 2020). This experiment, along with the other neutral transfer studies from the state transfer category supports a weak version of the specific sensorimotor representation theory suggesting, that the task that was initially practiced did not help in the performance of the transfer task. This is not comparable to a robust true negative transfer study, as those results demonstrate a decrement in motor performance on a transfer task. Neutral transfer results also do not fit within the generalizability of motor learning hypothesis because what was initially practiced did not have a positive gain to the transfer task.

In this situation, learning a wrist flexion and extension motor task with or without physical fatigue to the forearm does not impact the performance of the same motor task under the opposite condition which it was practiced under (i.e., physical fatigue practice switches to performing the motor task now without physical fatigue, and no-physical fatigue learning now switches to performing the motor task with physical fatigue) is deemed neutral transfer.

4.5.1 Movement Time (MT)

Based on the instructions of this task for participants to complete the waveform recreation as quickly and as accurately as possible, movement time (MT) was used as one of the measures of motor performance on this motor task. MT is an important measure in a continuous waveform tracking task as it can provide information about any speed-accuracy trade-off strategies in which participants engage. In this experiment, with speed remaining the same regardless of physical fatigue, the results do not support our hypothesis that the physical fatigue group would take longer overall on the motor task than the no-physical fatigue group. This would suggest, that as participants in the physical fatigue group became fatigued, their speed would also decrease in an attempt to maintain task accuracy, but this was not the case. All participants increased their speed on the motor task over time throughout acquisition. This is evidence that participants likely adopted a strategy of slowing down their movement to decrease their error.

Immediate retention provides insight into how well the motor skill has been acquired after practice. The immediate retention was tested by performance on the same waveform motor task, without waveform feedback. From the end of acquisition to immediate retention, there was no significant difference in MT. This demonstrates that there was no effect on participants' overall speed when feedback was removed during the same day as acquisition. The main interest with the immediate retention test is to use this as a better comparison for the delayed retention test. This way, an immediate retention test with no waveform feedback can be compared to a delayed retention test also with no waveform feedback. The implementation of an immediate retention test in addition to a delayed retention test is not always common practice in the motor learning literature, but can certainly be a useful tool to determine whether any effects are due to a consolidation period or the removal of feedback.

In the delayed retention test, approximately 24 hours following acquisition, participants have had the time to sleep and have the opportunity for a consolidation period to occur (see Karni et al., 1994; Walker et al., 2002). The consolidation period refers to behavioural correlates of memory, where under some conditions the neural substrate will become resistant to disruption over hours or days (Krakauer & Shadmehr, 2006). In other words, a significant positive correlation has been found between motor performance and the amount of sleep the learner has overnight (Walker et al., 2002). A review by Censor and colleagues (2012) reveals that motor learning experiments with a consolidation period including sleep result in the primary motor cortex going through experience-dependent reorganization which remains for months along with the motor behaviour gains. The studies included in the review by Censor et al. (2012) demonstrate that the relevant primary cortical areas have the capability to undergo neuroplastic changes during this offline learning time. This finding of sleep-dependent motor skill improvement has implications for the efficient learning of all motor skills in humans (Walker et al., 2002). In the 24-hour delayed retention test, performance remains the same and there is a consistent level of performance as it relates to MT, indicating that the practice that occurred on day one was not lost, and was maintained in the absence of waveform feedback on day two. This is consistent with the literature where the motor skill performance was sustained after a period of consolidation (Walker et al., 2002). Additional research has validated the use of 24-hour delayed retention test alongside a 48-hour delayed retention test and found that the amount of practice rather than the interval between practice sessions affected the consolidation and retention of a motor task (Yamada et al., 2019). This suggests that either the use of a 24-hour retention test, or a 48-hour retention test would have been sufficient, and a 24-hour retention test was used in the current experimental framework for participant scheduling efficiency.

In the transfer test, both groups have similar performance to their retention test, which also does not support the specificity of practice hypothesis and suggests that switching the fatigue condition has little effect overall. Having little effect suggests that the learned motor skill was neutral, and not specific. Specifically, as the sensorimotor context of the task changes, there is no difference from delayed retention to transfer as it relates to MT. This suggests that in this context of forearm physical fatigue, there was detriment with participants performing the same motor task, to the same skill level, with, or without forearm fatigue. The main analysis of the transfer test was used to determine whether there is any degree of motor skill specificity, from early acquisition compared to transfer reveals neither a significant improvement nor a decrement (neutral transfer). For the overall MT analysis, there was also no difference in the lack of interaction of group and block on MT. These analyses test the sensorimotor context hypothesis when the sensorimotor context is fundamentally changed as Proteau and colleagues (1987; 1992; 1998; 2002; 2005) and Starkes and colleagues (1993) suggest. Indeed, this experiment reveals no decrement or improvement in performance thereby suggesting flexibility of the motor system to adapt to those changes in sensorimotor contexts. In other words, in this experiment, the sensorimotor representations are not condition-specific.

4.5.2 Root mean square error

As the instructions to the participant were to ‘recreate the waveform to the best of your ability’, the amount of RMSE is reflective of the participants’ level of accuracy in a continuous target tracking task, with a higher value indicating worse accuracy. With MT, this can provide insight into any speed-accuracy trade-off strategies that may be adopted by the participants. In this study, each group performed at the same levels of accuracy regardless of being physically fatigued or not.

For RMSE as a function of time, participants improved their accuracy on the motor task in acquisition. This reveals that as participants are seeing their waveform feedback, they are improving performance accuracy throughout the 80 acquisition trials. This steep performance curve of the motor skill is common as mentioned in chapter one with the power law of practice (Snoddy, 1926). With any novel motor task, as learners receive intrinsic and extrinsic feedback, they will use this information to correct their motor performance and improve skill accuracy over time. In this experiment, participants viewed their waveform overlapped with the target waveform in the acquisition phase, and the results demonstrate that participants were quick to detect and correct their errors on the task.

For the immediate retention test, there was an increase in participants' performance accuracy compared to early in acquisition. This suggests that participants can continue to become more accurate in their movements after the removal of waveform feedback, indicating that the motor skill was successfully acquired. There is also an improvement from late acquisition to immediate retention which provides information about how their performance is improving because the task remains the same, with the only difference being the removal of waveform feedback. This result suggests that vision of the waveform feedback is no longer as important at this time point in the experiment relative to both early and late acquisition. Again, this immediate retention test is intended to help cross-compare the same-day no-feedback test to the 24-hour delayed no-feedback retention test.

As expected, the delayed retention test demonstrates an increase in RMSE compared to the immediate retention test. However, the main interest here is that the motor skill was retained based on the improvement since the start of acquisition which suggests relative permanence of having learned the motor task. This result is consistent with the literature that values the examination of the beginning of acquisition or baseline motor performance to retention test scores (Christina & Shea, 1988).

Overall performance from the start of acquisition to the transfer test demonstrates an improvement in motor performance, which is again contrary to the hypothesis and suggests motor skill generalizability to a different sensorimotor context. Similar to the MT findings, the measures of accuracy suggest that people perform better with time, however, changes in the sensorimotor context in terms of adding or removing physical fatigue does not hinder, and in some respects can help performance. This is in line with the theoretical perspectives of motor skill generalizability outlined in chapter one relating to transfer-appropriate processing (e.g., Lee, 1988; Schmidt & Bjork, 1992). Measures of learning are consistent because it is the same as the end of acquisition, but better than the beginning, and the total change of the sensorimotor context in terms of transfer actually helps accuracy, suggesting that the underlying processes developed in the task are not affected by the change in sensorimotor context, or the sensorimotor representations developed during acquisition are flexible and can adapt to change.

For the RMSE, there was no significant interaction of participants' physical fatigue and time throughout neither acquisition, immediate retention, delayed retention, nor transfer. Comparing the transfer test to early acquisition reveals no difference which suggests, contrary to the hypothesis, regardless of whether practicing the motor task was under the condition of being physically fatigued or not, had no impact on the error rates in a changed sensorimotor context switched to either with physical fatigue for the first time or without physical fatigue for the first time. The lack of interaction is indicative of performance inaccuracy for both groups. Although both groups improved in their motor performance accuracy during acquisition, they got more accurate at the same rate, and both groups maintained that level of accuracy across all three test conditions. This suggests that acquiring the motor task occurred independently of forearm physical fatigue levels.

4.5.3 Correlation

To further examine the relationship between speed and accuracy, Pearson *r* correlations between RMSE and MT were used across acquisition, immediate retention, delayed retention, and transfer. Typically, in this type of motor task, a negative correlation would be hypothesized, that as participants learn if they slow down (i.e., increase MT), they can be more accurate (i.e., decrease RMSE), providing insight into the speed-accuracy trade-off and if that strategy was adopted. However, there is no stable relationship found in this experiment between RMSE and MT. With neither the physical fatigue group nor the no-physical fatigue group showing significant correlations between RMSE and MT. This lack of correlation suggests that participants were not engaging in the speed-accuracy trade-off under these conditions. Importantly, this remained consistent for both groups, whether participants were physically fatigued or not during day one did not make a difference. This lack of correlation in the transfer tests too, suggests that participants in both groups were unaffected by the change in the sensorimotor contexts. This is inconsistent with specificity of practice theory literature (e.g., Proteau, 2005; Proteau et al., 1987, 1992, 1998; Proteau & Isabelle, 2002; Starkes et al., 1993; Woltz et al., 2000) and in line with the generalizability of motor learning theory literature (e.g., Adams, 1987; Broadbent, 1958; Craik & Lockhart, 1972; Morris et al., 1977; Schmidt, 1975; Thorndike, 1906) from chapter one. This indicates that in the context of forearm physical fatigue and a novel waveform task, the specificity of practice principle does not apply. One explanation as to why the speed-accuracy trade-off wasn't as prevalent as hypothesized is that there was not an explicit time goal to adhere to. Participants were instructed to complete the motor task as quickly and as accurately as possible, but there was no additional motivation for participants to want to maximize these speed and accuracy parameters.

4.5.4 Limitations

It is important to remember that this study occurred during the COVID-19 pandemic. Unprecedented restrictions on research meant that original lab-based research was halted, and a new virtual mode of research was designed and executed. Using portable, and deliverable equipment was favourable because it made data collection possible given our resources available, and created an environment that was resilient against the everchanging public health measures.

4.6 Conclusions

This research aimed to test the robustness of the state transfer category results supporting the sensorimotor representation theory by using the checklist from chapter two. Based on this investigative framework, our hypothesis that negative transfer would occur after learning under the context of forearm physical fatigue was not supported. The results indicate that participants performed the waveform motor task with similar speed and accuracy regardless of what physical fatigue condition they practiced under. Evidence from this experiment suggests that changing sensorimotor context is not detrimental to performance. This goes against the explanation of sensorimotor representation and supports the transfer-appropriate processing explanation that what is being acquired during acquisition is flexible and that the processing that is involved during acquisition is appropriate for transfer to different levels of musculature fatigue. Everything that is involved in the learning of a forearm waveform tracking task, regardless of whether the forearm is physically fatigued or not is flexible, adaptable, and generalizable to different sensorimotor environments. One possible explanation for our inability to observe specificity in our findings might relate to the concept of 'sensory dominance.' In our study, the intervention mainly aimed at altering the participants' physical fatigue, which has a direct impact on their proprioception, as indicated by research like that of Goodman and Tremblay (2018). During the motor task, vision was consistently available to the participants and served as the primary source of sensory information. This visual dominance remained unaffected by any changes in the context of the transfer task, suggesting that the reliance on visual cues over proprioceptive feedback might explain the lack of specificity observed.

Regardless of the results reported here, the use of this checklist is an important piece in demonstrating a suggested methodological structure for future studies in motor learning transfer research. This checklist can help with consistency in motor learning tests, the intervals of time between these tests, understanding the transfer test, and using and discussing appropriate measures throughout the experiment.

4.6.1 Investigative Framework

The checklist from chapter two is now addressed to conclude on its usefulness:

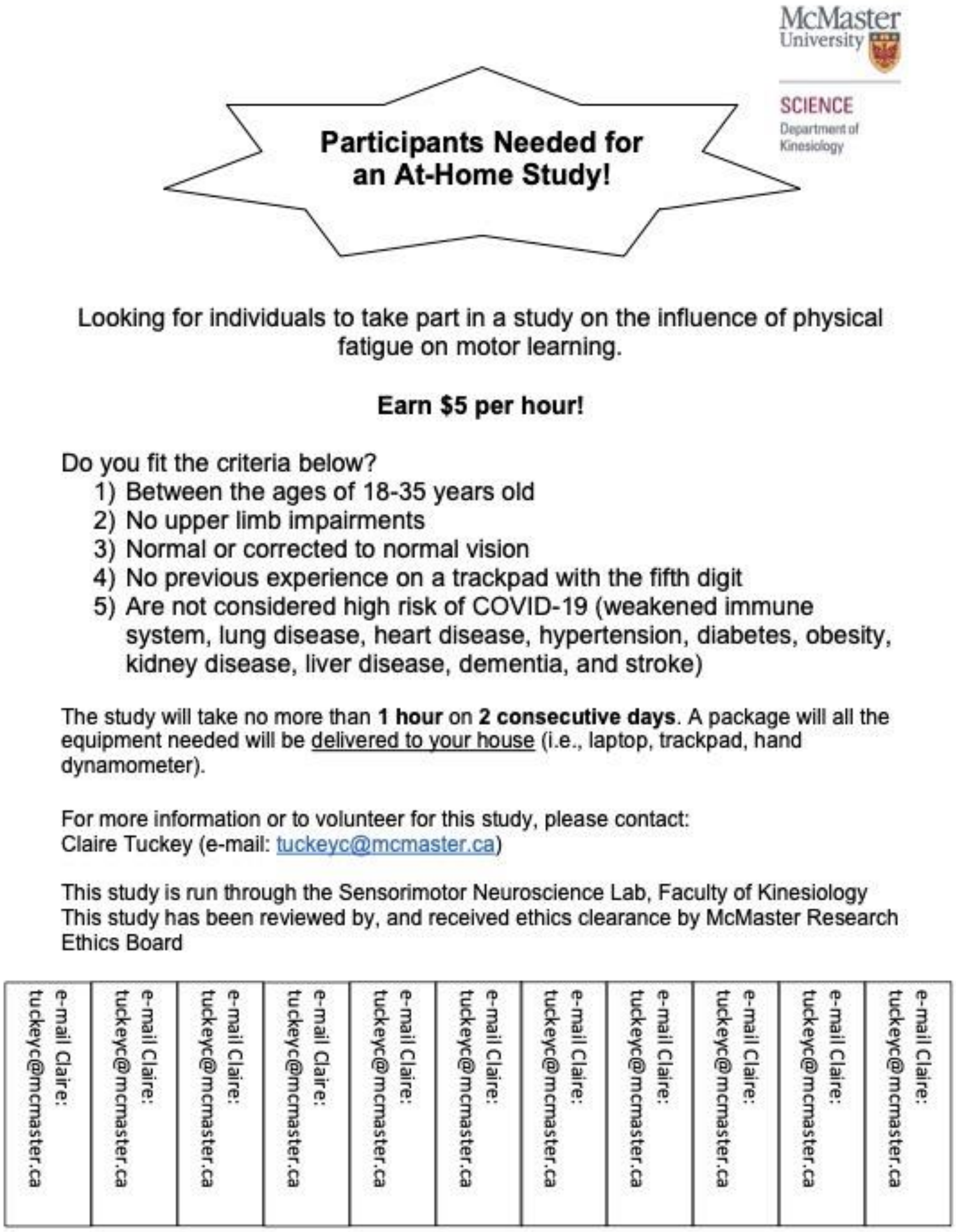
1) *Follow a traditional motor learning experimental protocol using acquisition, immediate retention test, delayed retention test (greater than or equal to 24 hours later), and transfer test,*
    - ☑ This timeline was followed using a motor skill acquisition period, an immediate retention test for a more direct comparison of feedback removal, and delayed retention and transfer tests being 24 hours later to allow for the consolidation period to occur.
2) *Understand and state the intentions of the transfer test, and what is the exact element that is being transferred. (What differs the transfer test from the delayed retention test, and select only one element to change),*
    - ☑ In this study, the intention of the transfer test is to transfer the physical fatigue under which participants trained. The delayed retention test maintained the exact same condition of physical fatigue and the exact

same motor task with the only difference from acquisition being the removal of waveform feedback. The transfer test has the same motor task, and the same removal of waveform feedback as the retention test, only changed the physical fatigue condition.

3) *Utilize the minimum independent and/or dependent variables of interest suitable for the motor task and research question being used,*
    - ☑ To maintain a simple study design, only MT and RMSE were examined as suitable variables for the motor task to be able to assess a speed-accuracy trade-off strategy. These variables were assessed between groups, across time, and between tests to best isolate the effect of the intervention.
4) *Utilize the Transfer Taxonomy language to allow for more consistent conclusion language being used in the motor learning literature.*
    - ☑ This study used 'state transfer' throughout describing the element that is being transferred. This specific language is used to help understand what is being transferred.

While the specificity of motor learning outcome was not observed in this experiment, more research is needed on the specificity of motor learning literature. Future research should continue to utilize this investigative framework design to elicit other salient forms of sensorimotor contexts. As discussed in chapter two, there are many types of transfer that have the prevalence to produce a specificity effect (i.e., equipment, feedback modality, expertise, anthropometrical, attentional, state, conditions of practice, and target/task transfers). Within the state transfer category that this experiment examined, more research is needed to further explore the different types of state transfer (e.g., physical fatigue, sleep, temperature, dopamine replacement medication, etc.) to see whether some types of state transfer are more likely to elicit specificity of motor learning than others. While chapter two was a comprehensive scoping review including all types of transfer, future research should examine each type of transfer and subcategories within the taxonomy. This investigative framework should be used as a basis for extracting whether or not the specificity of practice phenomenon exists through the motor skill transfer.

4.7 Appendix G – Participant recruitment poster



McMaster University

SCIENCE
Department of Kinesiology

Participants Needed for an At-Home Study!

Looking for individuals to take part in a study on the influence of physical fatigue on motor learning.

Earn $5 per hour!

Do you fit the criteria below?

1) Between the ages of 18-35 years old
2) No upper limb impairments
3) Normal or corrected to normal vision
4) No previous experience on a trackpad with the fifth digit
5) Are not considered high risk of COVID-19 (weakened immune system, lung disease, heart disease, hypertension, diabetes, obesity, kidney disease, liver disease, dementia, and stroke)

The study will take no more than **1 hour** on **2 consecutive days**. A package will all the equipment needed will be delivered to your house (i.e., laptop, trackpad, hand dynamometer).

For more information or to volunteer for this study, please contact:
Claire Tuckey (e-mail: tuckeyc@mcmaster.ca)

This study is run through the Sensorimotor Neuroscience Lab, Faculty of Kinesiology
This study has been reviewed by, and received ethics clearance by McMaster Research Ethics Board

e-mail Claire: tuckeyc@mcmaster.ca
e-mail Claire: tuckeyc@mcmaster.ca
e-mail Claire: tuckeyc@mcmaster.ca
e-mail Claire: tuckeyc@mcmaster.ca
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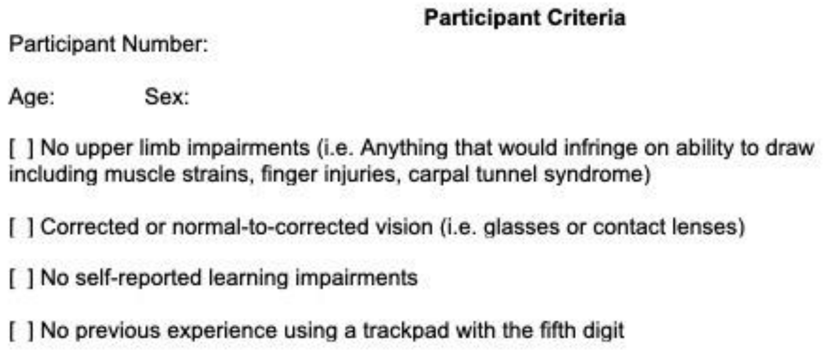
e-mail Claire: tuckeyc@mcmaster.ca

4.8 Appendix H – Participant criteria



Participant Criteria

Participant Number:

Age: Sex:

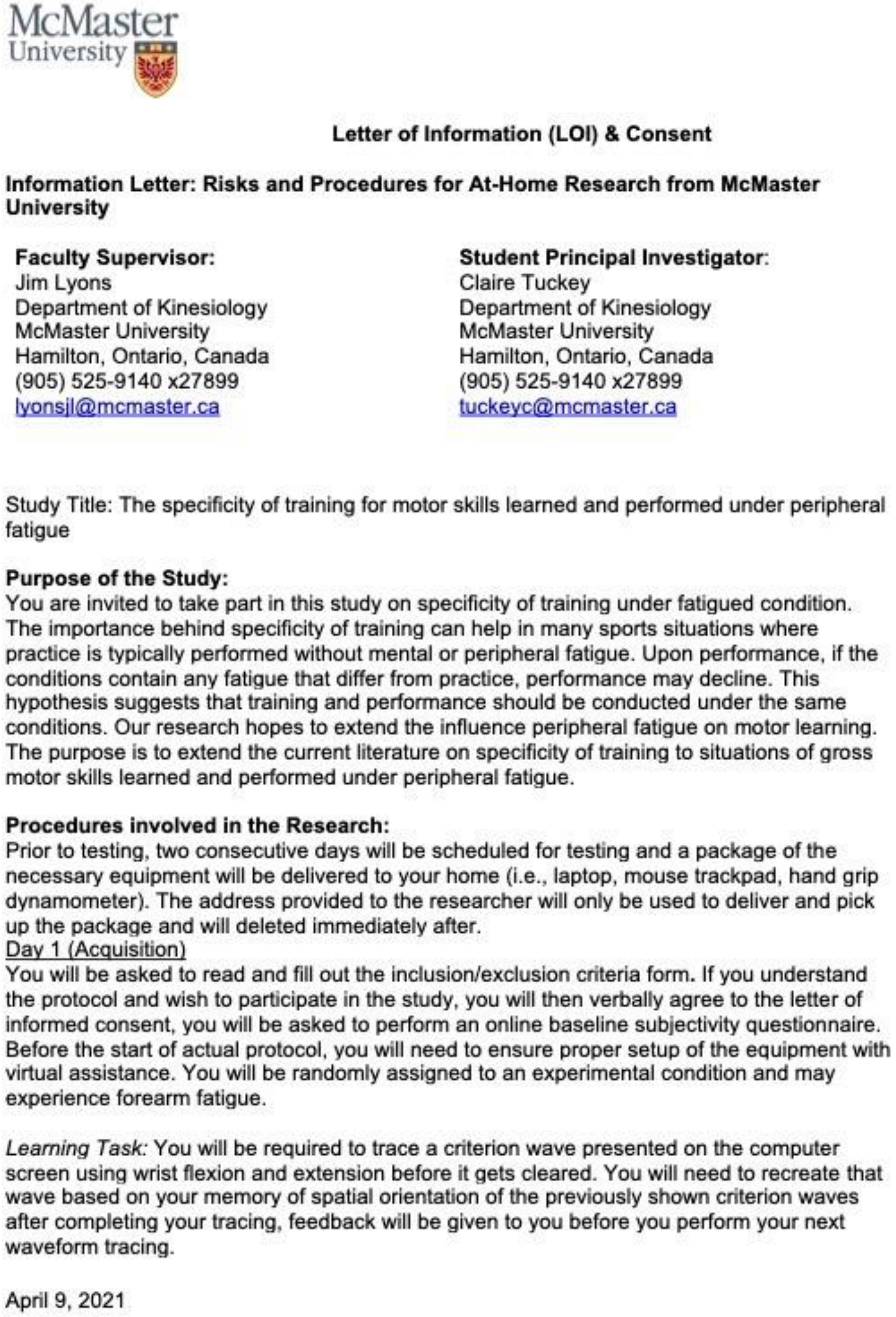
[ ] No upper limb impairments (i.e. Anything that would infringe on ability to draw including muscle strains, finger injuries, carpal tunnel syndrome)

[ ] Corrected or normal-to-corrected vision (i.e. glasses or contact lenses)

[ ] No self-reported learning impairments

[ ] No previous experience using a trackpad with the fifth digit

4.9 Appendix I – Letter of information and consent



McMaster University

Letter of Information (LOI) & Consent

Information Letter: Risks and Procedures for At-Home Research from McMaster University

Faculty Supervisor:
Jim Lyons
Department of Kinesiology
McMaster University
Hamilton, Ontario, Canada
(905) 525-9140 x27899
lyonsjl@mcmaster.ca

Student Principal Investigator:
Claire Tuckey
Department of Kinesiology
McMaster University
Hamilton, Ontario, Canada
(905) 525-9140 x27899
tuckeyc@mcmaster.ca

Study Title: The specificity of training for motor skills learned and performed under peripheral fatigue

Purpose of the Study:
You are invited to take part in this study on specificity of training under fatigued condition. The importance behind specificity of training can help in many sports situations where practice is typically performed without mental or peripheral fatigue. Upon performance, if the conditions contain any fatigue that differ from practice, performance may decline. This hypothesis suggests that training and performance should be conducted under the same conditions. Our research hopes to extend the influence peripheral fatigue on motor learning. The purpose is to extend the current literature on specificity of training to situations of gross motor skills learned and performed under peripheral fatigue.

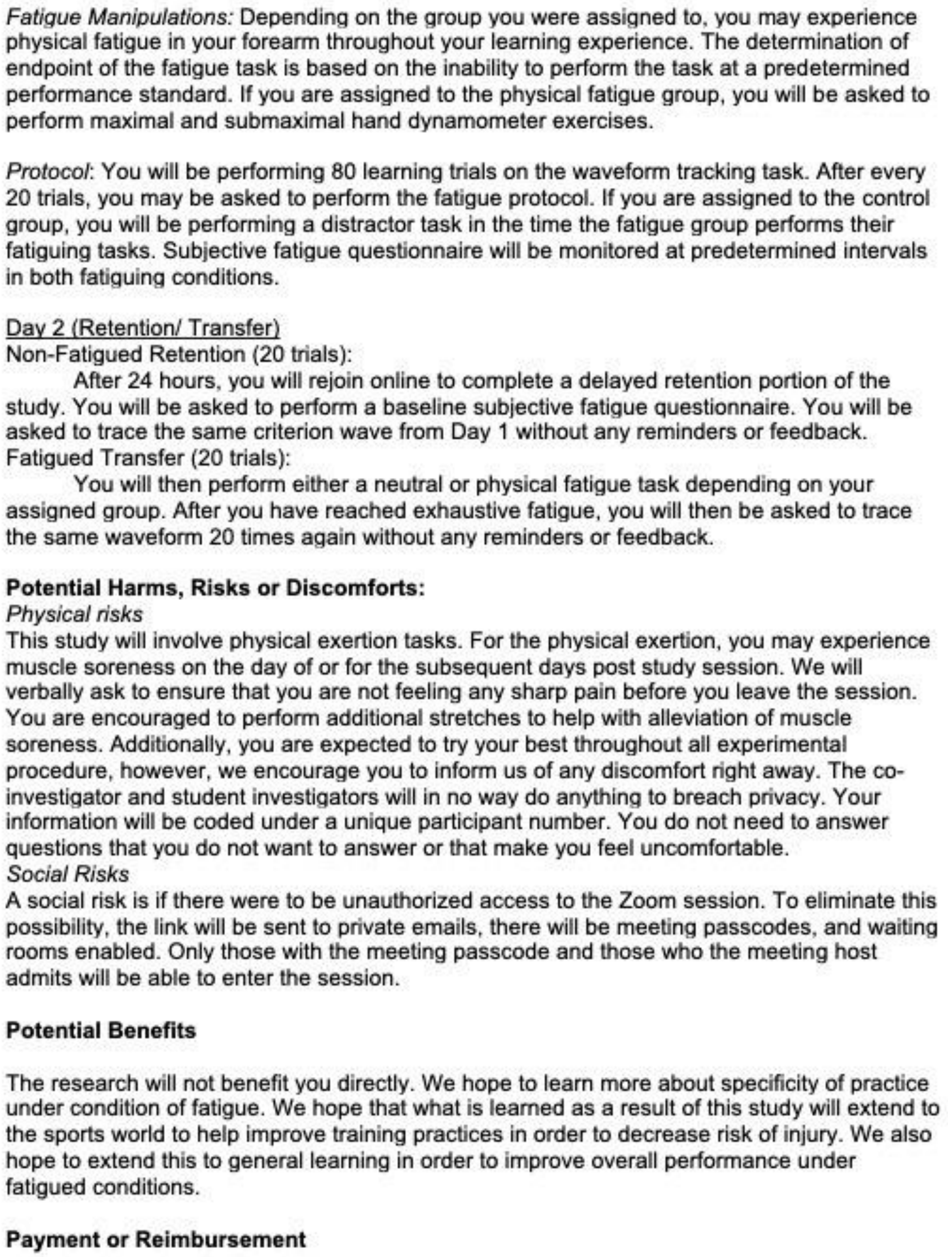
Procedures involved in the Research:
Prior to testing, two consecutive days will be scheduled for testing and a package of the necessary equipment will be delivered to your home (i.e., laptop, mouse trackpad, hand grip dynamometer). The address provided to the researcher will only be used to deliver and pick up the package and will deleted immediately after.

Day 1 (Acquisition)

You will be asked to read and fill out the inclusion/exclusion criteria form. If you understand the protocol and wish to participate in the study, you will then verbally agree to the letter of informed consent, you will be asked to perform an online baseline subjectivity questionnaire. Before the start of actual protocol, you will need to ensure proper setup of the equipment with virtual assistance. You will be randomly assigned to an experimental condition and may experience forearm fatigue.

Learning Task: You will be required to trace a criterion wave presented on the computer screen using wrist flexion and extension before it gets cleared. You will need to recreate that wave based on your memory of spatial orientation of the previously shown criterion waves after completing your tracing, feedback will be given to you before you perform your next waveform tracing.

April 9, 2021



Fatigue Manipulations: Depending on the group you were assigned to, you may experience physical fatigue in your forearm throughout your learning experience. The determination of endpoint of the fatigue task is based on the inability to perform the task at a predetermined performance standard. If you are assigned to the physical fatigue group, you will be asked to perform maximal and submaximal hand dynamometer exercises.

Protocol: You will be performing 80 learning trials on the waveform tracking task. After every 20 trials, you may be asked to perform the fatigue protocol. If you are assigned to the control group, you will be performing a distractor task in the time the fatigue group performs their fatiguing tasks. Subjective fatigue questionnaire will be monitored at predetermined intervals in both fatiguing conditions.

Day 2 (Retention/ Transfer)
Non-Fatigued Retention (20 trials):

After 24 hours, you will rejoin online to complete a delayed retention portion of the study. You will be asked to perform a baseline subjective fatigue questionnaire. You will be asked to trace the same criterion wave from Day 1 without any reminders or feedback.

Fatigued Transfer (20 trials):

You will then perform either a neutral or physical fatigue task depending on your assigned group. After you have reached exhaustive fatigue, you will then be asked to trace the same waveform 20 times again without any reminders or feedback.

Potential Harms, Risks or Discomforts:

Physical risks

This study will involve physical exertion tasks. For the physical exertion, you may experience muscle soreness on the day of or for the subsequent days post study session. We will verbally ask to ensure that you are not feeling any sharp pain before you leave the session. You are encouraged to perform additional stretches to help with alleviation of muscle soreness. Additionally, you are expected to try your best throughout all experimental procedure, however, we encourage you to inform us of any discomfort right away. The co-investigator and student investigators will in no way do anything to breach privacy. Your information will be coded under a unique participant number. You do not need to answer questions that you do not want to answer or that make you feel uncomfortable.

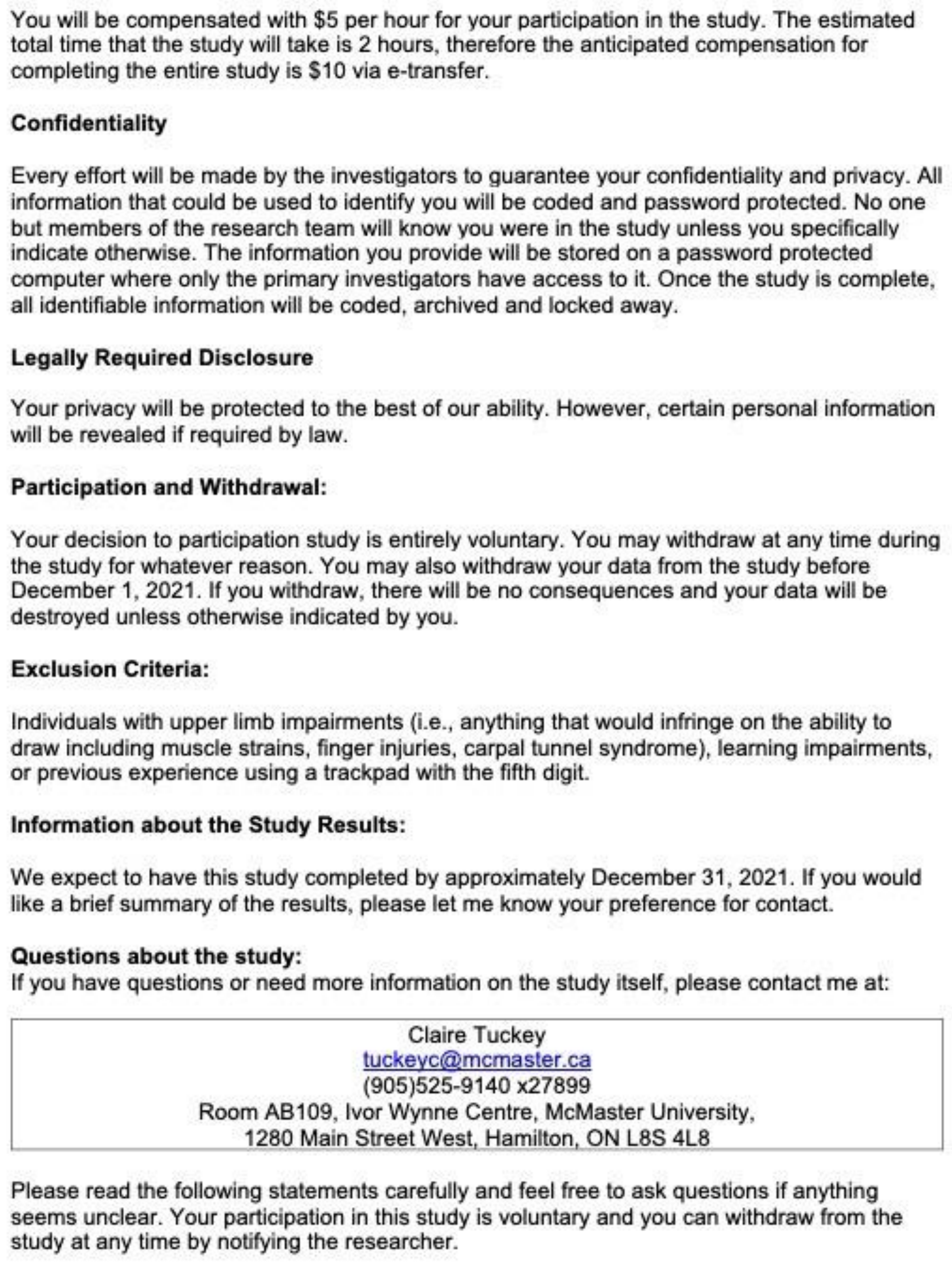
Social Risks

A social risk is if there were to be unauthorized access to the Zoom session. To eliminate this possibility, the link will be sent to private emails, there will be meeting passcodes, and waiting rooms enabled. Only those with the meeting passcode and those who the meeting host admits will be able to enter the session.

Potential Benefits

The research will not benefit you directly. We hope to learn more about specificity of practice under condition of fatigue. We hope that what is learned as a result of this study will extend to the sports world to help improve training practices in order to decrease risk of injury. We also hope to extend this to general learning in order to improve overall performance under fatigued conditions.

Payment or Reimbursement



You will be compensated with $5 per hour for your participation in the study. The estimated total time that the study will take is 2 hours, therefore the anticipated compensation for completing the entire study is $10 via e-transfer.

Confidentiality

Every effort will be made by the investigators to guarantee your confidentiality and privacy. All information that could be used to identify you will be coded and password protected. No one but members of the research team will know you were in the study unless you specifically indicate otherwise. The information you provide will be stored on a password protected computer where only the primary investigators have access to it. Once the study is complete, all identifiable information will be coded, archived and locked away.

Legally Required Disclosure

Your privacy will be protected to the best of our ability. However, certain personal information will be revealed if required by law.

Participation and Withdrawal:

Your decision to participation study is entirely voluntary. You may withdraw at any time during the study for whatever reason. You may also withdraw your data from the study before December 1, 2021. If you withdraw, there will be no consequences and your data will be destroyed unless otherwise indicated by you.

Exclusion Criteria:

Individuals with upper limb impairments (i.e., anything that would infringe on the ability to draw including muscle strains, finger injuries, carpal tunnel syndrome), learning impairments, or previous experience using a trackpad with the fifth digit.

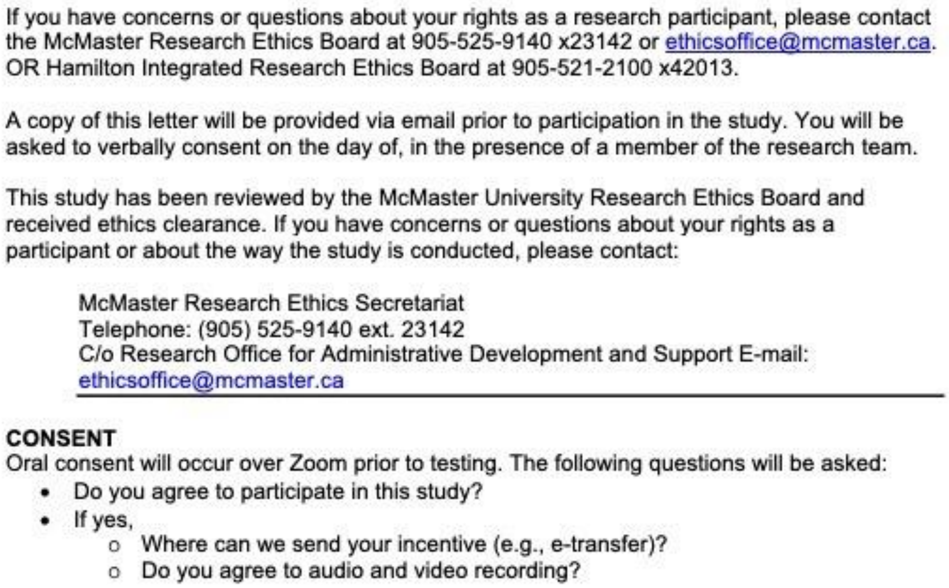
Information about the Study Results:

We expect to have this study completed by approximately December 31, 2021. If you would like a brief summary of the results, please let me know your preference for contact.

Questions about the study:
If you have questions or need more information on the study itself, please contact me at:

Claire Tuckey
tuckeyc@mcmaster.ca
(905)525-9140 x27899
Room AB109, Ivor Wynne Centre, McMaster University,
1280 Main Street West, Hamilton, ON L8S 4L8

Please read the following statements carefully and feel free to ask questions if anything seems unclear. Your participation in this study is voluntary and you can withdraw from the study at any time by notifying the researcher.



If you have concerns or questions about your rights as a research participant, please contact the McMaster Research Ethics Board at 905-525-9140 x23142 or ethicsoffice@mcmaster.ca. OR Hamilton Integrated Research Ethics Board at 905-521-2100 x42013.

A copy of this letter will be provided via email prior to participation in the study. You will be asked to verbally consent on the day of, in the presence of a member of the research team.

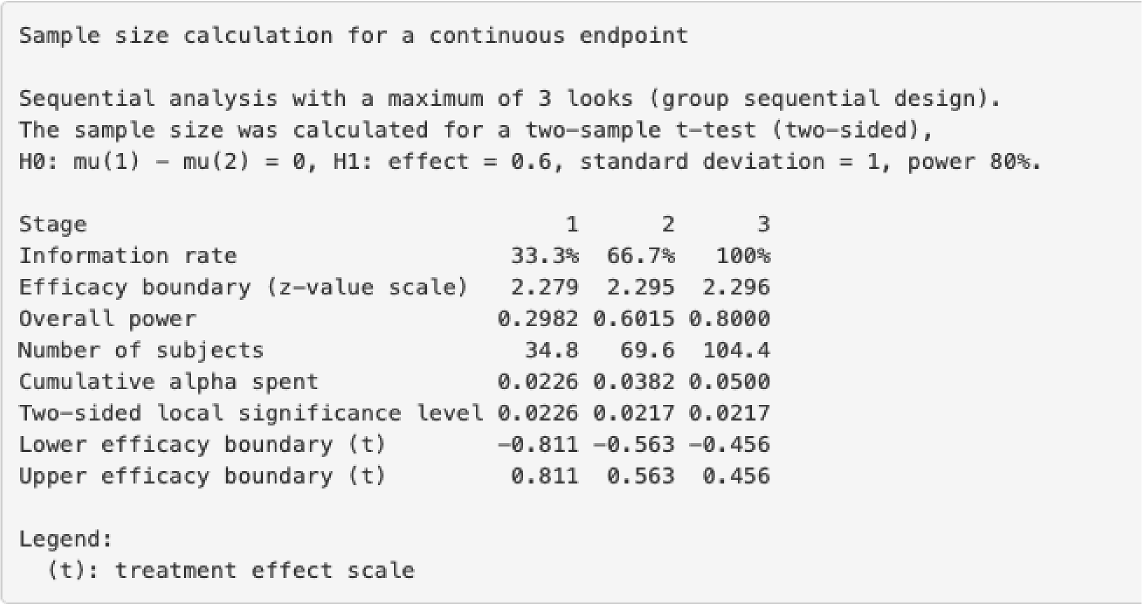
This study has been reviewed by the McMaster University Research Ethics Board and received ethics clearance. If you have concerns or questions about your rights as a participant or about the way the study is conducted, please contact:

McMaster Research Ethics Secretariat
Telephone: (905) 525-9140 ext. 23142
C/o Research Office for Administrative Development and Support E-mail:
ethicsoffice@mcmaster.ca

CONSENT
Oral consent will occur over Zoom prior to testing. The following questions will be asked:

- Do you agree to participate in this study?
- If yes,
  - Where can we send your incentive (e.g., e-transfer)?
  - Do you agree to audio and video recording?

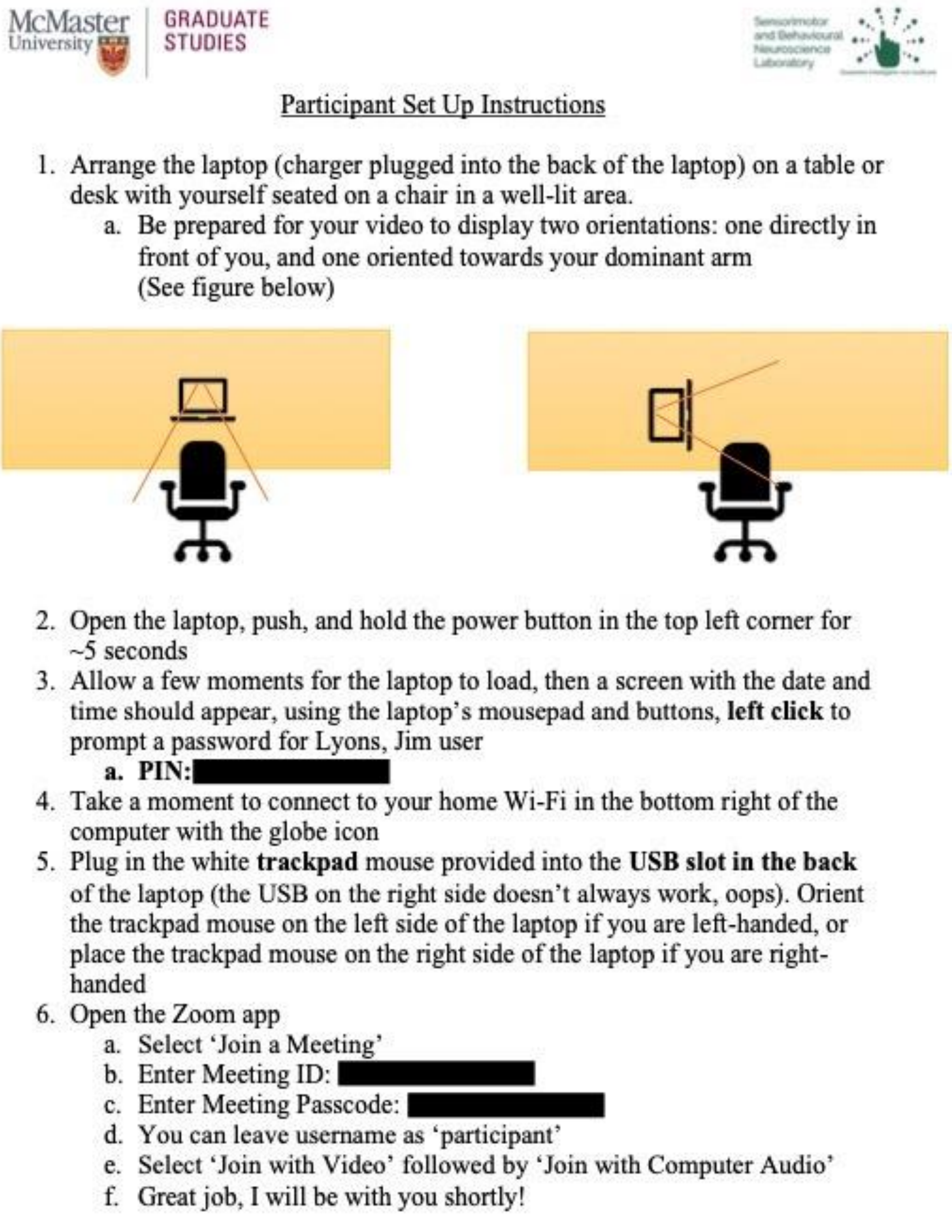
4.10 Appendix J – Pocock alpha spending function calculation



```
Sample size calculation for a continuous endpoint

Sequential analysis with a maximum of 3 looks (group sequential design).
The sample size was calculated for a two-sample t-test (two-sided),
H0: mu(1) - mu(2) = 0, H1: effect = 0.6, standard deviation = 1, power 80%.

Stage                                   1      2      3
Information rate                    33.3%  66.7%   100%
Efficacy boundary (z-value scale)   2.279  2.295  2.296
Overall power                      0.2982 0.6015 0.8000
Number of subjects                   34.8   69.6  104.4
Cumulative alpha spent             0.0226 0.0382 0.0500
Two-sided local significance level 0.0226 0.0217 0.0217
Lower efficacy boundary (t)        -0.811 -0.563 -0.456
Upper efficacy boundary (t)         0.811  0.563  0.456

Legend:
  (t): treatment effect scale
```

Screenshot of the rpact Shiny app output

4.11 Appendix K – Participant set up instructions



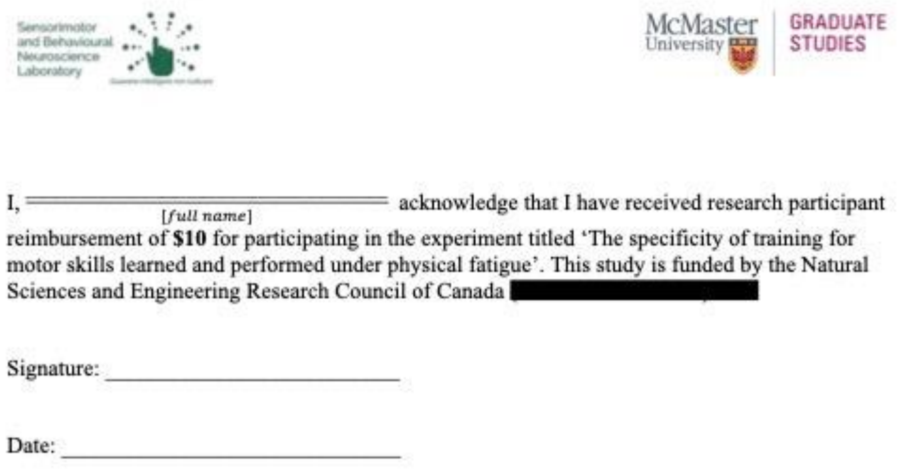
McMaster University | GRADUATE STUDIES

Sensorimotor and Behavioural Neuroscience Laboratory

<u>Participant Set Up Instructions</u>

1. Arrange the laptop (charger plugged into the back of the laptop) on a table or desk with yourself seated on a chair in a well-lit area.
    a. Be prepared for your video to display two orientations: one directly in front of you, and one oriented towards your dominant arm (See figure below)
2. Open the laptop, push, and hold the power button in the top left corner for ~5 seconds
3. Allow a few moments for the laptop to load, then a screen with the date and time should appear, using the laptop's mousepad and buttons, **left click** to prompt a password for Lyons, Jim user
    a. PIN: [redacted]
4. Take a moment to connect to your home Wi-Fi in the bottom right of the computer with the globe icon
5. Plug in the white **trackpad** mouse provided into the **USB slot in the back** of the laptop (the USB on the right side doesn't always work, oops). Orient the trackpad mouse on the left side of the laptop if you are left-handed, or place the trackpad mouse on the right side of the laptop if you are right-handed
6. Open the Zoom app
    a. Select 'Join a Meeting'
    b. Enter Meeting ID: [redacted]
    c. Enter Meeting Passcode: [redacted]
    d. You can leave username as 'participant'
    e. Select 'Join with Video' followed by 'Join with Computer Audio'
    f. Great job, I will be with you shortly!

4.12 Appendix L – Participant reimbursement form



Sensorimotor and Behavioural Neuroscience Laboratory

McMaster University GRADUATE STUDIES

I, ______________________________ acknowledge that I have received research participant reimbursement of **$10** for participating in the experiment titled 'The specificity of training for motor skills learned and performed under physical fatigue'. This study is funded by the Natural Sciences and Engineering Research Council of Canada [redacted]

[*full name*]

Signature: ________________________

Date: ___________________________

CHAPTER 5: GENERAL DISCUSSION

5.1 Summary of research aims

The motor learning literature for the past 65 years has been filled with distinct lines of research for motor skill generalizability and specificity of practice. Motor skill generalizability provides learners with a positive gain from a previously learned motor task on the transfer to a new task and is supported by the massive evidence of transfer-appropriate processing theory (e.g., Lee, 1988; R. Schmidt & Bjork, 1992). Specificity of practice refers to a decrement in performance from a previous motor task to the transfer of a new motor task and has less evidence of support as reflected in the chapter two scoping review. These spaces rarely mix, and there have been no clear boundaries for when a motor skill is more likely to be generalizable, and when it is more likely to be specific to the contexts it was practiced under. Unpacking these distinctions are important for coaches, clinicians, teachers, parents, and individuals to have a greater understanding of how our practiced motor tasks can transfer to other motor tasks.

The main aims of this thesis address these gaps by examining where the specificity of practice exists, whether there are commonalities between the specificity of practice experiments, and creating a robust procedure for future researchers examining the specificity of practice phenomenon.

5.1.1 Summary from Chapter Two (Scoping Review)

To examine the specificity of practice experiments that exist within the motor learning literature, a broader scope of studies was required from the start of the search to be able to understand the whole story of specificity of practice. The scoping review in this thesis examines all studies with a transfer test which allows for one of four outcomes: positive transfer, neutral transfer, negative transfer, or mixed results. In doing so, all motor learning experiments with the opportunity for negative transfer were examined, and the specificity of practice experiments was contrasted to the generalizability experiments for further comparisons. These comparisons give information about whether or not there were any commonalities that were unique to the specificity of practice experiments compared to the generalizability experiments. Chapter two results reveal sporadic accounts of both positive and negative motor transfers across the taxonomy. While specific conclusions cannot be made as to which types of transfer are more likely to lead to generalizability or specificity, solid advances have been made to organize this literature to demonstrate what the state of the literature currently is, and to expand on language use in future motor learning transfer research. It is valuable to have a scoping review at this time because it will organize the research that has been done to date. This can give researchers a better understanding of the scope of the literature and where current understandings of generalizability and specificity are, and what the limitations are.

The limitations found when developing the scoping review in chapter two were the foundation of creating a checklist for sound motor learning transfer protocol design in chapter three. This checklist from chapter two is a four-item document designed to ensure that an experiment that follows this checklist will be able to come to more definitive conclusions as to whether or not the specificity of practice hypothesis exists under the chosen intervention. It is valuable to have a structure to follow when designing a motor learning transfer experiment as many experiments found in chapter two ended in the ‘mixed results’ category that are a function of not adhering to these recommendations.

5.1.3 Summary from Chapter Four (Protocol)

The empirical research in chapter four is designed to apply the checklist from chapter three to create a sound methodology for future researchers examining the specificity of practice. This experimental framework uses a robust motor learning methodology to isolate a clear opportunity for negative transfer to be revealed. This methodology became a central pillar for this thesis; by considering the limitations learned, and the checklist in chapter two, providing a proof-of-concept study in chapter four, future research can leverage this design to test and clearly interpret important questions and outcomes in motor learning. To clarify, this protocol is not designed to ensure a specificity of motor learning effect, it is designed to maximize the opportunity to isolate the specificity effect if it exists in the chosen intervention.

5.2 Application

To our knowledge, chapter two is the most expansive and recent scoping review that covers a cross-disciplinary examination of the motor learning transfer literature to date. Key findings from chapter two, particularly limitations in the literature, can be leveraged by future research to use the checklist outlined in chapter three. The scoping review from chapter two uncovered common themes that are of relevance to motor learning and kinesiology researchers. In the past 65 years, there has been a lack of consistent language being used in the motor learning literature. A review in 1984 by Salmoni and colleagues viewed more than 250 motor learning studies and was remarkable in terms of the array of disparate tasks and measures of performance that were used, claiming “making it difficult to compare results across studies” p. 359. By expanding on the work included in their review by examining research over the past 36 years, based on findings from chapter two, it is clear that the motor learning area of research is still having issues in this regard. By design, a strategy behind the scoping review was to keep the inclusion criteria as broad as possible without sacrificing fundamental motor learning criteria (i.e., greater than or equal to 24-hour retention test duration) to allow for disciplines outside of motor learning research by trade to meet the inclusion criteria with a version of a transfer test. In allowing for this, the scope of the scoping review was not limited to traditional motor learning studies and covered any motor task facilitating the review to cross disciplines, and making the taxonomy language applicable to other kinesiology-related domains. The types of experiments included in the scoping review varied from rehabilitation to sports and athlete populations. With such variety in the types of studies included in the scoping review, the application to kinesiology researchers also broadens. Chapter two streamlined language, and includes many different populations of interest making the findings applicable to many different contexts.

The checklist from chapter three covers what methodological steps should take place to allow for specificity of motor learning effect to occur in full salience. The items in this checklist, such as following a traditional motor learning experimental protocol using acquisition, immediate retention test, delayed retention test (greater than or equal to 24 hours later), and transfer test are not new concepts in motor learning research, but based on the results of the scoping review in chapter two, it was time for a reminder. Coming back to these traditional motor learning experimental protocol designs can promote clearer results in future transfer of motor learning research.

The application of the empirical work in chapter four applied key points from the scoping review and applies the checklist from chapter three to the creation of a protocol-based experiment. The intention of the experiment from chapter four is to present a sound protocol with a clear opportunity for specificity of practice to be displayed. Chapter four is intended to be a sample protocol where the intervention can be modified to contain any context of interest. In modifying the intervention, though it remains important to maintain the items outlined in the chapter three checklist. With these checklist items in place, the intervention of choice will have the opportunity to display whether or not it supports the specificity of the motor learning hypothesis. The absence of significant results in chapter four demonstrates how difficult it is to reveal specificity of practice effects when the study is held to the most exacting and stringent methodological standards. Where specificity of practice effects are expected to be seen, based on work by Proteau (2005); Proteau and colleagues (1987, 1992, 1998); Proteau and Isabelle (2002) the results of chapter four do not reveal them. While the specificity of practice contexts differ from this thesis (i.e., physical fatigue) to the work by Proteau and colleagues (i.e., vision), a promising future direction would be to consolidate the ideas from this thesis (e.g., checklist) with the reproduction of Proteau and colleagues' experiments. With the added checklist elements, this could only help confirm the little information that we do know about the specificity of practice effect on motor tasks.

5.3 Limitations and future directions

The studies in this dissertation explored the specificity of practice hypothesis. This is only one theoretical perspective as to why negative transfer occurs based on limited evidence that supports this hypothesis, compared to overwhelming support for transfer-appropriate processing. The specificity of practice hypothesis was examined in this dissertation to further explore why the theory is so rare. The little evidence supporting this theory compared to the ample evidence in favour of the transfer-appropriate processing theory by nature only provides limited studies to compare (i.e., 19 experiments outlined in the negative transfer chart). With little evidence supporting the specificity of practice hypothesis, in comparison to the ample evidence in favour of the transfer-appropriate processing theory; the disparity in the evidence available is likely due to the lack of advantages in creating a specificity of motor learning context as outlined in chapter one. As well, the purpose behind this scoping review is to solely examine the scope of the experiments and is not a meta-analysis. Therefore, details around appropriate sample sizes, power, and effect sizes were not included. Future research should consider creating a meta-analysis around the specificity of motor learning experiments from chapter two. A meta-analysis would be helpful to provide a better understanding of the experiments that claim specificity of motor learning and can dive into more information regarding the sample sizes used, power, and how strong the effects are.

Another limitation of the experiment conducted in chapter four is the unprecedented COVID-19-related restrictions and disruptions. In August of 2020, our third committee meeting approved data collection for the original proposed experiment in-person. Unbeknownst to us at the time, the COVID-19 pandemic would persist, and in-person research would be shut down again. Two more committee meetings in 2021 would approve a virtual-modified version of the original experiment. The intention with the virtual-modified version is to still address the same research questions but in a portable, at-home version for all parties' health and safety. The virtual protocol is a favourable step in this dissertation because it made data collection resilient against the everchanging public health measures including the potential for additional lockdowns and restrictions for in-person activities. A limitation to the switch from in-person data collection to driving to individual participants’ houses multiple times negated the experiment from being taken to the 100% information rate of the sample size due to time and resource restrictions. The experimental data from chapter four was conducted with participants during the summer and fall of 2021. During this time, research in person was permitted, but with the uncertainty of when the next lockdown would occur and with limited vaccination rollouts. With this uncertainty, data collection was converted into a portable protocol that was manually delivered and picked up from each participant’s home. This was able to ensure a contact-free data collection for researcher and participant safety but also presented new limitations. Any troubleshooting issues that may have been resolved easily in an in-person setting were now in the hands of the participants and as a result, more data points and participants were removed. The nature of the portable equipment required swift delivery and pick-up times to maximize the amount of participant scheduling per week. Despite the limitations presented due to COVID-19, it is important to consider the efforts made to provide a protocol that closely matches the original in-person equipment and protocol plans to answer the same research question.

Future directions from the outcome of this dissertation hope to encourage motor learning and kinesiology researchers to be attentive to the language that is used throughout the descriptions of the transfer test outcomes. Language from the taxonomy in chapter two will be helpful when discussing research from across disciplines. Greater consistency in the language used can help with organizing and interpreting results from 65 years of motor learning research and can lend to comparisons between studies that can be made to draw more direct themes and impacts in the field of motor learning. To learn more about the impactfulness of the results, a meta-analysis on the specificity of motor learning studies would be an impactful future direction of this work. Building on the limitations from chapter four, another future direction the field should consider is to reinforce the importance of ensuring a consolidation period in future motor learning experiments. Without the opportunity for relative permanence to occur, then the study becomes a motor performance study and learning can no longer be inferred from the results.

5.4 Conclusions

The original research presented within this dissertation investigates the specificity of practice hypothesis. Each chapter has made novel contributions to the literature by providing a taxonomy to improve the consistency of discussion communication and language when cross-comparing studies, creating a checklist for future specificity of motor learning experiments, and providing a demonstration of this checklist in a proof-of-concept protocol. This work was able to isolate the motor learning studies that demonstrate the specificity of practice under the inclusion criteria set by the scoping review. This dissertation also provides a useable list of limitations in experiments that demonstrate the specificity of practice or generalizability to aid with future motor learning experiments. In its entirety, this dissertation provides organization and recommendations to the scattered 65 years of research on the specificity of practice.

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