Impact of Self-Controlled Practice on Motor Learning for Individuals with Post-Stroke Upper Limb Hemiparesis

Lauren Beth Winterbottom

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Abstract

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Upper limb (UL) impairments are common after stroke and can lead to loss of independence and long-term disability. Motor learning interventions for individuals with stroke can improve UL function and engagement in daily activities. Self-controlled practice (SCP) involves allowing choice during motor skill practice and has been shown to improve motor learning in healthy adults as well as individuals with Parkinson's disease. Additionally, SCP may impact psychological outcomes, including intrinsic motivation, self-efficacy, and positive affect. Although SCP has been incorporated into complex stroke rehabilitation interventions, little is known about its specific impact on motor learning for individuals with stroke. The purpose of this study is to investigate the effect of SCP on motor learning and psychological outcomes for adults with chronic UL impairment after stroke.

Sixteen participants with chronic UL impairment due to stroke were paired and randomized into two groups. All participants practiced a standardized motor task with both their more affected and less affected hands for two consecutive days. During each day of practice, participants completed 50 30-second trials (10 blocks of 5 trials each) with their more affected hand and 20 30-second trials (10 blocks of 2 trials each) with their less affected hand. The experimental group was given control over their practice schedule and chose the order they practiced blocks of trials. Participants in the control group followed a pre-determined practice schedule based on the choices made by the participant they were paired with in the experimental

group. Outcome measures were assessed on Day 1 before practice (Pre-Test), Day 2 after practice (Post-Test), and Day 3 (Follow-up). Motor learning outcomes included 24-hour retention of the trained motor task and immediate (10-minute) and delayed (24-hour) transfer of learning to an untrained motor task. Psychological outcomes including intrinsic motivation, self-efficacy, and positive affect were also assessed.

Both groups demonstrated significant improvements from baseline on both the trained task and the untrained task at the Day 3 follow-up assessment. There were no significant between-group differences on any motor learning or psychological outcome measures. However, there was a significant association between perceived choice that was assessed on Day 2 following practice and amount of change on the untrained transfer task at Day 3. This suggests that perception of choice may be a relevant factor for motor learning after stroke. However, more research with larger sample sizes is needed to further investigate this finding.

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Dedication

To my parents, for your unconditional love and support.

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In memory of Dr. Jane Case-Smith, for encouraging me to become an OT.

Chapter 1: Introduction

Stroke is a devastating disease that impacts millions of people worldwide and is a common cause of long-term disability (Feigin et al., 2021; Virani et al., 2021). Stroke results from impaired perfusion in blood vessels of the brain. Lack of blood and oxygen supply to neural tissue leads to ischemic stroke while blood vessel rupture causes hemorrhagic stroke (Kuriakose & Xiao, 2020). Stroke can cause sensorimotor deficits of the upper limb (UL) that are contralateral to the lesion, such as weakness, changes in muscle tone, and loss of normal patterns of coordination (Roby-Brami et al., 2021). These deficits are often persistent and contribute to reduced participation in daily activities, necessitating rehabilitation efforts to improve arm function (Guidetti et al., 2014; Houwink et al., 2013; Winstein et al., 2016a). Improvements in functional use of the more affected UL can be limited by a tendency to compensate with the less affected arm, leading to learned nonuse (Taub & Wolf, 1997). Learned nonuse of the UL is common after stroke, with individuals reporting low motivation to use their more affected arm due to repeated experiences of failure and inability to use their arm properly during daily activities (Ballester et al., 2022b; Meadmore et al., 2019). This is problematic because, after stroke, a large dosage of intensive practice is required for motor learning to occur, and repeated arm use throughout the day is essential for regaining function (Cirstea et al., 2003; Kleim & Jones, 2008).

Rehabilitation interventions that increase motivation and engagement during practice may help elicit motor learning and improve functional recovery of the UL (Sánchez & Winstein, 2021). Motivated practice stimulates the dopaminergic rewards system in the brain, which is crucial for motor learning (Speranza et al., 2021). Activation of dopaminergic neurons can increase the perceived value and reduce the perceived cost of a given action, making long-term

goal attainment possible by enhancing cognitive control (Cools et al., 2019). Following a stroke, research has shown that the dopaminergic rewards system is under-activated, which may negatively impact motor learning (Widmer et al., 2019). However, interventions designed to stimulate the dopaminergic rewards system during motor practice have demonstrated improvements in motor learning and recovery for stroke survivors, suggesting that the dopamine system may be an important target in stroke rehabilitation interventions (Quattrocchi et al., 2017; Widmer et al., 2022).

Research in stroke rehabilitation has led to the development of complex interventions that employ motor learning principles to help improve function in the more affected arm during daily use (Jeon et al., 2015; Winstein et al., 2014). While these interventions can lead to improvements in arm function, they have not been shown to be superior to usual practice, and there is evidence that arm use is limited even after treatment (Ballester et al., 2022b; Sánchez & Winstein, 2021; Winstein et al., 2016b; Winstein & Varghese, 2018). Complex stroke rehabilitation interventions incorporate multiple principles of motor learning to elicit reacquisition of functional motor skills. These principles are generally derived from research with healthy subjects and animals (Kleim & Jones, 2008; Maier et al., 2019; Winstein et al., 2014; Winterbottom & Nilsen, 2024). However, when some of these principles have been tested individually, stroke survivors have responded differently than healthy individuals, while other principles have not specifically been tested with the stroke population (Gregor et al., 2021; Hayward et al., 2014; Maier et al., 2019). Thus, the degree to which the individual components of complex interventions contribute to improvements in motor recovery is largely unknown. Testing the impact of these specific variables on motor learning can help determine the active ingredients within complex interventions. Clinicians can then focus on these active ingredients during treatment and potentially improve outcomes.

For example, practice conditions that support learner autonomy have been shown to facilitate motor learning and are thought to support interest and enjoyment in the activity (Wulf & Lewthwaite, 2016). Self-controlled practice (SCP) is a specific type of autonomy support in which the learner is given control over a practice condition during motor practice (Sanli et al., 2013) and has been integrated into multi-faceted stroke rehabilitation approaches (Lewthwaite et al., 2018; Winstein et al., 2016b). Making choices according to one's preferences may activate the dopaminergic rewards system, thereby improving memory consolidation and motor learning (Wulf & Lewthwaite, 2016). This may also improve self-regulation during the experience of failure, which may help inhibit negative emotions and support resilience when practicing challenging activities (Legault & Inzlicht, 2013; Murayama et al., 2015). SCP is believed to improve motor learning by increasing the learner's focus on the task goal as well as their belief in the potential for success (Wulf & Lewthwaite, 2016). Expected success may improve psychosocial factors such as self-efficacy and positive affect, which have been shown to predict motor learning outcomes (Chiviacowsky et al., 2012a; Wulf et al., 2018; Wulf & Lewthwaite, 2016).

Numerous studies with healthy participants have shown that SCP improves motor skill retention and transfer of learning for a variety of different practice conditions, including control over the practice schedule, or the order in which different tasks are practiced (Sanli et al., 2013; Wulf & Lewthwaite, 2016). In addition to healthy individuals, both older adults and individuals with Parkinson's disease have also been shown to benefit from SCP (Chiviacowsky et al., 2012b; Lessa & Chiviacowsky, 2015). While SCP has been integrated into complex stroke rehabilitation interventions for UL rehabilitation (Lewthwaite et al., 2018; Winstein et al., 2016b), little is known about the specific impact of SCP on motor learning for individuals with UL impairments

after stroke. Thus, more research is needed to determine if SCP is an active ingredient in complex stroke rehabilitation interventions.

The purpose of this study was to learn about the effects of SCP on motor learning and psychological factors such as intrinsic motivation, self-efficacy, and positive affect for individuals with chronic (> 6 months) post-stroke UL impairment. In SCP research, each member of the experimental group (EG) is paired with someone in the control group (CG). The EG is given control over a specific practice condition while the CG follows a pre-determined schedule based on choices made by the EG (Sanli et al., 2013; Wulf & Lewthwaite, 2016). In this study, participants were paired and randomized into either EG or CG. All participants practiced a standardized simulated self-feeding task for two consecutive days with both their more affected and less affected hands. Participants in the EG were given control over their practice schedule (i.e. the order that they practice blocks of trials with each of their hands), while participants in the CG followed a pre-determined practice schedule based the choices made by the EG participant with whom they were paired. Outcomes were assessed on Day 1 before practice (Pre-Test), Day 2 after practice (Post-Test), and Day 3 (Follow-up). The aims of this study were to learn about the impact of SCP on motor learning for individuals with UL hemiparesis after stroke, measured by retention of a trained task and transfer of learning to an untrained task, as well as the impact of SCP on intrinsic motivation, self-efficacy, and positive affect.

Chapter 2: Background

2.1 Sensorimotor Deficits after Stroke

Sensorimotor deficits in the UL after stroke are often persistent and can contribute to long-term disability (Guidetti et al., 2014; Virani et al., 2021). Motor learning interventions have been developed to address deficits such as weakness, spasticity, and impaired interjoint coordination (Levin, 1996; Li & Francisco, 2015). Impaired neural signaling can result in abnormal muscle tone and function, causing a reduction in UL movement coordination (Sánchez & Winstein, 2021). Loss of active movement can cause problematic changes in soft tissue function, including tendon shortening and joint contracture, leading to increased UL impairment (Roby-Brami et al., 2021). UL movement is often characterized by reduced speed and smoothness, muscle co-contraction, abnormal flexor synergy patterns, and difficulty performing complex interjoint movements, limiting coordination during functional use (Dewald et al., 1995; Levin, 1996; Levin & Demers, 2021; Roby-Brami et al., 2021; Winterbottom & Nilsen, 2024). For instance, stereotypic movement patterns involving abduction and internal rotation of the shoulder and flexion of the elbow limit access to functional reaching space (Dewald et al., 1995; Roby-Brami et al., 2021). As a result, individuals with post-stroke hemiparesis may compensate for limited range of motion during reaching with excessive motion in their trunk in order to access objects in the environment. Other compensatory strategies may include grasping objects from above with a downwardly rotated palm or sliding the hand across the table (Roby-Brami et al., 2021). Finger movement is often limited by increased activation of the long finger flexors and reduced control over the intrinsic muscles in the hand; additionally, flexor coupling between fingers and thumb commonly makes individuated finger movements even more challenging (Lang & Schieber, 2004; Roby-Brami et al., 2021). These deficits limit the ability to form

functional grasping patterns that enable manipulation of a variety of task objects in reachable space.

Sensory deficits are also common after stroke and contribute to impairments in hand and arm function. For example, those without proprioception have much greater difficulty learning and retaining new motor skills (Rowe et al., 2017). Reduced light touch and pressure sensation can make it challenging to manipulate objects and apply the appropriate amount of grip force, requiring compensation from the visual system (Roby-Brami et al., 2021). Additionally, impaired pain and temperature sensation can lead to safety concerns during functional hand use.

2.2 Motor Learning and Stroke

Motor Learning Definitions

Motor learning refers to performance improvement in a skill following practice or experience, which is exhibited by increased speed and accuracy during skill execution (Magill & Anderson, 2021). Several distinct types of motor learning are relevant for stroke rehabilitation interventions, including 1) the acquisition of a novel motor skill, 2) motor sequence learning, 3) improvements in movement quality, and 4) motor adaptation (Krakauer et al., 2019). While the research described in this dissertation is focused on acquisition of a novel skill (or, for individuals with post-stroke UL impairment, reacquisition of a previously learned skill), brief definitions of the other types of motor learning are also provided below.

Acquisition of Novel Skills. Motor learning can involve developing a new pattern of coordination, such as learning a tennis serve; this requires the learner to perform numerous repetitions of the skill to discover the most effective and efficient methods of performing the task (Bernstein, 1967; Krakauer et al., 2019). Novel skill acquisition is often a goal in motor learning research studies that seek to determine which practice conditions are most advantageous in

improving a given skill. After stroke, individuals may lose the ability to perform previously acquired motor skills that are needed for daily activities, making it necessary to relearn these skills through practice. For example, functional reaching performance can be limited by poor interjoint coordination, which can be defined as impaired spatial and temporal organization of degrees of freedom during goal-oriented movements (Tomita et al., 2017). In order to relearn UL coordination patterns for functional skills, many repetitions of the movement are needed to elicit improvements in skilled performance (Cirstea et al., 2003). In this study, participants engaged in repetitive practice of a simulated feeding task to increase the speed of task completion.

Sequence Learning. Many daily activities rely on performing sequences of movements where the underlying motor skill has already been developed (Bernspång & Fisher, 1995; Newell, 1985; Schambra et al., 2019). For example, typing words on a keyboard requires a specific sequence of movements. Daily activities often involve performing sequences of discrete motor skills in order to complete a complex task. For instance, preparing a meal requires a number of motor skills (e.g., reaching, grasping, manipulating, transporting, stabilizing) that must be performed sequentially in a logical order. Execution of these activities requires cognitive processing to organize performance as well as adequate motor abilities to carry out the steps of the task, which are often challenging after stroke (Bernspång & Fisher, 1995; McEwen et al., 2015). While sequence learning is important to consider in the reacquisition of complex daily activities after stroke, it is not the focus of this dissertation.

Improvements in Movement Quality. Changes in movement quality can also indicate skill improvements through changes in accuracy and precision of movements (Krakauer et al., 2019). For UL performance after stroke, movement quality can be quantified through kinematic measures to determine if normal movement patterns have been restored; however, current

methods are limited in their ability to distinguish between motor recovery and compensation (Saes et al., 2022). Stroke survivors with UL impairment often tend to compensate for motor impairments by using their trunk or alternative motor strategies (Roby-Brami et al., 2021). This may limit motor recovery and can encourage maladaptive use of the UL (Raghavan, 2015). Thus, consideration of movement quality is important in stroke rehabilitation, and attention should be given not only to task completion but also the quality with which movements are performed. However, this dissertation does not address this problem.

Motor Adaptation. Finally, motor adaptation involves making implicit adjustments in response to external perturbations in order to maintain motor performance during a task (Krakauer et al., 2019). Motor adaptation paradigms have been used in stroke rehabilitation to augment error during motor performance in order to help to normalize performance of the functional skill (Dzewaltowski et al., 2021; Quattrocchi et al., 2017). For example, split-belt treadmill training can improve asymmetrical step lengths in stroke survivors by increasing the speed of the treadmill belt being used by the hemiparetic leg. This adjustment increases the error in step length asymmetry for the user and forces them to adapt by taking larger steps, which can lead to more symmetrical step lengths following training (Dzewaltowski et al., 2021). However, again, motor adaptation is not investigated in this dissertation.

Motor Learning Measurement

This current study used a 24-hour retention test as well as immediate (10-minute) and delayed (24-hour) transfer tests to measure motor learning. A retention test involves performing the practiced task following a period of no practice to demonstrate persistence in the skill over time (Magill & Anderson, 2021). This study had a 24-hour retention period, which is common in motor learning studies for the stroke population (Gregor et al., 2021). Transfer tests can also be

used to assess motor learning. This involves testing a variation of the practiced skill in order to determine the learner's adaptability (Magill & Anderson, 2021). While transfer tasks are used infrequently in motor learning studies with the stroke population (Gregor et al., 2021), practicing one task has been shown to lead to improvements in an untrained skill for this population (Kantak et al., 2017; Schaefer et al., 2013). In this study, transfer of learning to an untrained task was measured immediately following completion of practice (immediate transfer) and 24-hours after completing the practice (delayed transfer).

Motor Learning Principles for Neurorehabilitation

Motor learning principles for neurorehabilitation have been applied in numerous interventions for stroke rehabilitation that are focused on improving UL motor function and performance in daily activities (Maier et al., 2019). These principles were developed through movement science research as well as advances in neuroscience and are focused on augmenting experience-dependent neural plasticity following brain injury to support skill reacquisition and motor recovery (Kleim & Jones, 2008; Maier et al., 2019; Winstein et al., 2014). Motor learning occurs through practice of a given skill. Practice conditions including practice variability, specificity, and amount have been studied to determine which variables enhance retention and transfer of motor skills (Magill & Anderson, 2021). Selected practice conditions that are relevant to this dissertation are described below. Psychosocial factors, such as having a sense of autonomy and having enhanced expectancies for future success have also been shown to significantly influence motor learning (Wulf & Lewthwaite, 2016). Additional motor learning principles for neurorehabilitation are described in detail by Maier and colleagues (2019) and Gregor and colleagues (2021). Additionally, Kleim and Jones (2008) describe principles of experience-dependent neural plasticity for post-stroke rehabilitation, which include motor

learning principles such as salience, specificity, repetition, and intensity. Please see Winterbottom and Nilsen (2024) for a summary of these principles, including dosage, verbal instruction, augmented feedback, problem solving, level of difficulty, and cognitive strategies to augment motor learning.

Practice Variability. Practice variability is the degree to which the learner practices variations of a motor skill, such as differences in movements or contexts. In research with healthy individuals, incorporating variability into practice has been shown to improve motor learning. Practice schedules, or in the order in which tasks are practiced, can be organized to increase variability. For example, a random practice schedule, where tasks are practiced in a random order, has high variability while a blocked practice schedule, where each task is practiced separately, has low variability. Motor learning research has found that random practice improves motor learning more than blocked practice with healthy individuals (Magill & Anderson, 2021). However, results of studies that have investigated the benefits of random vs. blocked practice with individuals after stroke are mixed, so any motor learning benefits are unclear for this population (Gregor et al., 2021). Practice variability is relevant to this dissertation because participants in the experimental group were given control over their practice schedule and, thus, had differing degrees of variability in their practice schedules. In order to control for potential effects of differences in variability on motor learning, each participant in the control group completed a practice schedule that was determined by a participant in the experimental group.

Task Specificity. Motor abilities are task specific, so in order to improve a skill, the actual task must be practiced. This principle is widely supported by research with healthy individuals as well as stroke survivors (Kleim & Jones, 2008; Magill & Anderson, 2021; Maier

et al., 2019). Practicing a specific task can also transfer to improvements on an untrained task if the two tasks have similar characteristics (Magill & Anderson, 2021). Schaefer and colleagues (2013) demonstrated this principle with individuals with chronic hemiparesis post-stroke. They found that repetitive practice of a simulated feeding task led to improvements on both the trained task and an untrained task that was kinematically similar. The study described in the dissertation used the trained and untrained tasks described by Schaefer and colleagues (2013) because both tasks were shown to be responsive to change following practice.

Amount of Practice. Sufficient amount of practice is needed for motor learning to occur, and, in general, more practice typically leads to better retention (Magill & Anderson, 2021). Research has shown that stroke survivors require an increased number of repetitions to improve a motor skill when compared to healthy individuals (Cirstea et al., 2003), so the amount of practice should be carefully considered when designing motor learning research for individuals after stroke. Schaefer and colleagues (2013) demonstrated that practicing a simulated feeding task for five consecutive days (50 trials per day) led to improvements in both a simulated feeding task and an untrained task for individuals with post-stroke UL hemiparesis. Visual inspection a graph of the training data from this study suggested that the largest improvements occurred during the first two days of training. Thus, in the study described in this dissertation, participants practiced the same simulated feeding task for two consecutive days (50 trials each day).

Motor Recovery and Neuroplasticity

Many complex interventions for UL stroke rehabilitation incorporate motor learning principles to elicit motor recovery. Motor recovery occurs when normal coordination patterns are regained from before the neurological disease or injury, such as stroke. This contrasts with compensation, in which new patterns of movement are developed that are less efficient and may

be influenced by abnormal synergies (Joy & Carmichael, 2021). Motor recovery varies among individuals and is associated with the severity of the stroke, the amount of time post-stroke, the integrity of the corticospinal tract, and other factors including psychological health, co-morbidities, and genetics (Alawieh et al., 2018). Neuroplasticity involves nervous system reorganization, which results from experience (Cramer et al., 2011). Following stroke, new neural connections are formed via synaptogenesis as the individual attempts to regain independence as they navigate their environment (Kleim & Jones, 2008). Motor recovery can take place through practice; however, movement compensations are quite common and can lead to the development of learned non-use and/or maladaptive movement patterns of the more affected side (Raghavan, 2015; Taub & Wolf, 1997). Research with animals has shown that the primary motor cortex reorganizes following repetitive practice of a novel motor task (Kleim et al., 1998; Plautz et al., 2000). Similarly, constraint-induced movement therapy, which involves intensive task-specific practice with the more affected UL, can lead to increased cortical grey matter volume after stroke and improve functional use of the limb (Gauthier et al., 2008). Thus, incorporating motor learning principles into stroke rehabilitation interventions, such as specificity, intensity, salience, and challenge, can help drive neuroplasticity and support UL motor recovery (Kleim et al., 1998; Maier et al., 2019).

Motor Learning Differences After Stroke

There are noted differences in motor learning between healthy individuals and those with hemiparesis after stroke. For instance, after stroke, more repetitions are needed to improve a motor skill than for healthy individuals (Cirstea et al., 2003), and motor learning may be masked by spasticity (Subramanian et al., 2018). Explicit instructions, which involve telling someone *how* to perform a movement, also have a negative impact on individuals after stroke that is not

observed with healthy individuals (Boyd & Winstein, 2006). In another example, while numerous studies have found that an external focus of attention (i.e., focusing on the goal of the task rather than on the body) benefits motor learning for healthy individuals, this finding has not been replicated for individuals with stroke (Kal et al., 2019; Kal et al., 2015; Kim et al., 2017). The benefits of other types of practice conditions, such as the distribution of practice and the optimal amount of variability, are also unclear for stroke survivors (Gregor et al., 2021).

In stroke rehabilitation, multiple motor learning principles are often incorporated into a single complex intervention. For example, Winstein and colleagues (2014) developed the Accelerated Skill Acquisition Program for post-stroke UL recovery based on motor learning and neuroscience research. Much of this research was done with healthy individuals or animals, and little is known about how stroke survivors respond to some of the specific principles that are incorporated into the intervention (e.g., self-controlled practice). Because stroke survivors may respond differently to motor learning principles than healthy individuals or animals, the effects of individual components within complex interventions should be tested with stroke survivors to determine if they have a positive effect on motor learning.

Motor Learning and the Dopaminergic Rewards System

The dopaminergic rewards system in the brain is crucial for motor learning, motor control, and memory. Dopaminergic neurons arising from the ventral tegmental area (VTA) in the midbrain connect with limbic and cortical areas of the brain via mesocorticolimbic pathways. These pathways are part of the neural rewards circuitry (Speranza et al., 2021) and are implicated in motor learning (Bradley & Damiano, 2019; Gower & Tiberi, 2018). However, the dopaminergic rewards system has been shown to be under-activated after stroke, which may negatively influence motor learning and recovery (Bradley & Damiano, 2019; Widmer et al.,

2019). This system helps the individual determine which actions are worth the effort, based on the potential rewards. Activating dopaminergic neurons can increase the perceived value and reduce the perceived cost of a given action. This can improve cognitive control, making long-term goal attainment easier (Cools et al., 2019).

After stroke, a great deal of high intensity practice is needed to support motor learning and recovery; however, stroke survivors may have reduced motivation to use their affected limb in functional activities, potentially due to high amounts of effort that do not lead to desired outcomes (Ballester et al., 2022a; Meadmore et al., 2019). As such, interventions that support optimal levels of motivation may help to elicit motor learning (Wulf & Lewthwaite, 2016). Intrinsic motivation involves engaging in an activity due to enjoyment in the activity itself. In contrast, extrinsic motivation occurs when external rewards or punishments drive participation (Deci & Ryan, 2008). Extrinsically motivating factors, such as monetary rewards, have been shown to improve motor learning and recovery after stroke (Quattrocchi et al., 2017; Widmer et al., 2022). However, interventions that use extrinsically motivating variables may also reduce the desire to engage in the activity once the external reward is withdrawn (Murayama et al., 2010). Because stroke survivors already report reduced motivation to use their more-affected arm in daily activities, interventions that promote intrinsic motivation with arm use may be important for supporting UL practice and participation in daily activities (Meadmore et al., 2019; Sánchez & Winstein, 2021).

2.3 Theoretical Applications

Self-Determination Theory

Self-Determination Theory (SDT) proposes that fulfillment of basic psychological needs (autonomy, competence, and relatedness) can improve performance and learning by eliciting

intrinsic motivation (Deci & Ryan, 2008). Having a sense of control over the environment and making decisions according to one's preferences can support an individual's sense of autonomy and improve task performance (Legault & Inzlicht, 2013; Leotti et al., 2010). Allowing choice during practice of a motor task may also help improve self-regulation when receiving feedback about failure, thereby increasing resilience and supporting continued engagement (Legault & Inzlicht, 2013; Murayama et al., 2015). Exerting control over the environment may help inhibit negative emotional responses during stressful situations and increase engagement during task practice (Leotti et al., 2010). Thus, giving choices may help support intrinsic motivation and learning during practice with the more affected UL (Lewthwaite et al., 2018; Meadmore et al., 2019; Sánchez & Winstein, 2021).

OPTIMAL Theory of Motor Learning

The OPTIMAL Theory of Motor Learning is supported by extensive motor learning research that was primarily conducted with healthy individuals. This theory incorporates constructs from SDT and hypothesizes that autonomy, perceptions of competence, and external focus of attention enhance motor learning (Wulf & Lewthwaite, 2016). Self-controlled practice (SCP) is one type of autonomy-supportive condition in which participants are able to make choices during practice of a motor task (Sanli et al., 2013). According to the OPTIMAL Theory, SCP may help increase focus on the task goal and belief in the potential for success. Expected success can then lead to further success, aiding in memory consolidation through activation of the dopamine system (Wulf & Lewthwaite, 2016). Research that has investigated the effects of SCP on motor learning allows the experimental group to make choices about a specific practice condition during motor skill practice. The control group is then yoked to the choices made by the

experimental group and follows a pre-determined practice schedule (Sanli et al., 2013; Wulf & Lewthwaite, 2016).

2.4 Self-Controlled Practice

Numerous studies with healthy subjects have shown benefits of SCP for both motor skill retention and transfer with a variety of types of practice conditions, including control over amount of practice (Lessa & Chiviacowsky, 2015; Post et al., 2011), when to use an assistive device (Chiviacowsky et al., 2012b), practice difficulty (Leiker et al., 2016; Pathania et al., 2019), when to receive feedback (Kaefer et al., 2014; Sanli et al., 2013), and practice schedule (Halperin et al., 2017; Iwatsuki et al., 2017; Keetch & Lee, 2007; Wu & Magill, 2011; Wulf & Adams, 2014). While this research has largely been conducted with young healthy adults when learning a novel motor skill, benefits of SCP have also been found for skilled athletes performing a well-learned skill (Halperin et al., 2017), individuals with Parkinson's disease (Chiviacowsky et al., 2012b), both introverts and extroverts (Kaefer et al., 2014), and older adults (Lessa & Chiviacowsky, 2015). Autonomy-supportive instructional language has been shown to improve motor learning, positive affect, self-efficacy, and perceived control when compared to controlling language during acquisition of a novel motor skill (Hooyman et al., 2014). Choices that are unrelated to practice conditions (incidental choices) can also provide a significant motor learning benefit. For example, choice in color of a mini golf ball or a factor completely unrelated to the task such as room decoration can lead to significant improvements in motor learning (Lewthwaite et al., 2015). Incidental choice has been shown to improve both motor learning outcomes and positive affect, suggesting that these two outcomes may be linked (Wulf et al., 2018). Positive affect refers to a positive emotional state or mood (e.g., happy, pleased, satisfied, contented) and can be measured using the Self-Assessment Manikin scale (Bradley & Lang,

1994; see section 3.3 for a description of the Self-Assessment scale). Supporting positive affect may facilitate motor learning through activation of the dopamine system (Di Domenico & Ryan, 2017; Wulf et al., 2018). Autonomy-support during motor task practice may also enhance self-efficacy, which has been shown to predict motor learning outcomes (Chiviacowsky et al., 2012a; Hooyman et al., 2014).

Neural Mechanisms of Self-Controlled Practice

Making choices during SCP may stimulate the dopamine system through activation of value-coding and salience-coding dopaminergic neurons (Di Domenico & Ryan, 2017). Dopamine projections from the VTA to the nucleus accumbens, the prefrontal cortex, and the primary motor cortex are part of the reward circuitry and enhance motor learning processes (Gower & Tiberi, 2018; Wulf & Lewthwaite, 2016). The ventromedial prefrontal cortex (vmPFC) encodes confidence and value in choices based on the potential anticipated rewards and is co-activated with the ventral striatum during decision-making (Hebscher & Gilboa, 2016). The vmPFC may also mitigate fear-based responses from the amygdala, which can help support emotional regulation and increase resilience (Hiser & Koenigs, 2018; Murayama et al., 2015). Autonomy may also help the learner self-regulate negative affective responses when errors are made (Legault & Inzlicht, 2013). vmPFC activation may also be linked with a reduced stress response from the dorsal raphe nucleus in the brainstem, lowering cortisol levels and increasing active coping (Maier et al., 2019; Sinha et al., 2016). After stroke, SCP has the potential to support continued engagement in task practice, even when failure is experienced.

SCP and autonomy-supportive interventions may also support cognitive engagement and information processing during task practice. Healthy subjects demonstrated increased EEG theta coherence and theta power during SCP when compared to those in the control condition, who did

not make choices related to their practice, suggesting that having control over practice conditions may elicit improvements in working memory and central executive activity (Jaquess et al., 2020, 2021). In addition, it has been suggested that SCP may reduce cognitive workload in more difficult practice environments (Pathania et al., 2019). The potential cognitive benefits of SCP may be helpful for individuals after stroke, as reduced attentional capacities are associated with non-use of the affected arm (Buxbaum et al., 2020). Autonomy supportive interventions may therefore help support information processing and cognitive engagement for stroke survivors during task practice, thereby improving motor learning potential.

Self-Controlled Practice and Stroke Rehabilitation

SCP may be an important active ingredient in stroke rehabilitation interventions that are focused on improving skill acquisition and motor learning. Interventions that support intrinsic motivation, positive affect, and self-efficacy may elicit increased engagement in stroke rehabilitation interventions. Complex autonomy-supportive interventions for stroke have been shown to improve quality of life, accelerate UL recovery, and increase transfer of learning to untrained tasks (Fu et al., 2020; Lewthwaite et al., 2018; McEwen et al., 2015). Additionally, there is evidence that stimulating the dopaminergic rewards system during motor practice may improve motor learning and recovery after stroke (Quattrocchi et al., 2017; Widmer et al., 2022). Control over practice conditions may improve resilience and persistence during task practice (Hebscher & Gilboa, 2016; Hiser & Koenigs, 2018; Legault & Inzlicht, 2013; Leotti et al., 2010). This is important as, after stroke, people have reported difficulty finding the motivation to incorporate their arm into daily activities, which may be due to repeated experiences of failure (Ballester et al., 2022b; Meadmore et al., 2019).

Although motivation is commonly recognized as an essential element in stroke rehabilitation (Kleim & Jones, 2008; Maier et al., 2019), the construct is rarely measured in interventions that are designed to enhance it (Rohrbach et al., 2019). Measuring the effect of SCP on intrinsic motivation, positive affect, and self-efficacy can help identify important targets for motor learning interventions. While motor learning research for stroke has often focused on how clinicians should structure practice for their patients, allowing stroke survivors to control aspects of their practice may help increase autonomy and engagement during participation in challenging and intensive interventions (Cools et al., 2019; Deci & Ryan, 2008). Incorporating choice into stroke rehabilitation interventions may also make practice more interesting and enjoyable, promoting continued persistence in the task (Deci & Ryan, 2008; Lewthwaite et al., 2018; Murayama et al., 2015). SCP is a relatively simple idea that could be incorporated into a variety of developing interventions for stroke rehabilitation if there is sufficient evidence to demonstrate that it improves motor learning. For instance, it could potentially enhance the effectiveness of rehabilitation interventions that use technology (e.g., active gaming, virtual reality, and robotics) by supporting intrinsic motivation and enhancing skill acquisition.

2.5 Research Questions

The purpose of this study was to examine the effect of SCP on motor learning and on psychological variables, including intrinsic motivation, positive affect, and self-efficacy for individuals with UL hemiparesis after stroke. This study may offer evidence that can be used to develop future interventions for stroke survivors with UL hemiparesis. The research questions for this study are:

1. Does control over practice schedule (i.e. the order in which blocks of trials are performed) improve motor learning for individuals with UL hemiparesis after stroke?

a. Hypothesis 1: The experimental group, who will have control over the practice schedule while practicing a motor task for two days, will demonstrate greater 24-hour retention of a trained motor task when compared to the control group, who will not have control over the practice schedule.
b. Hypothesis 2: The experimental group will demonstrate greater immediate (10-minute) and delayed (24-hour) transfer of learning during the performance of an untrained motor task when compared to the control group.

2. Does control over practice schedule increase intrinsic motivation, positive affect, and self-efficacy for individuals with UL hemiparesis after stroke?
    a. Hypothesis 3: The experimental group will demonstrate greater intrinsic motivation, positive affect, and self-efficacy after practicing the motor task at the Day 2 post-test than the control group.

Chapter 3: Methods

3.1 Study Design

This study was designed to evaluate the effect of SCP on motor learning for individuals with UL hemiparesis after stroke. Participants were paired and randomized into experimental and control groups. Both groups practiced a functional motor task for two consecutive days with their more and less affected arms. The experimental group was given control over the practice schedule (the order in which blocks of trials were practiced with each arm), while the control group followed a pre-determined schedule based on choices made by the experimental group participant they were paired with. Outcomes were assessed on Day 1 before training (pre-test), on Day 2 after training (post-test), and on Day 3 (follow-up). This study was conducted in the research laboratory of the Department of Rehabilitation and Regenerative Medicine at Columbia University Irving Medical Center (CUIMC). The protocol was approved by the Columbia University Institutional Review Board (IRB-AAAU1704) and the Teachers College Institutional Review Board (IRB ID: 23-348). All procedures, including informed consent, were conducted in accordance with IRB policies and ethical guidelines.

3.2 Participants

Participants were adults with chronic (> 6 months) UL hemiparesis due to ischemic or hemorrhagic stroke. Inclusions/exclusion criteria was as follows:

Inclusion Criteria:

- Age 40-75
- Chronic (>6 months) post-stroke UL hemiparesis
- History of ischemic or hemorrhagic stroke
- Box and Block Test (BBT) score of 3-60 on the affected side

- Intact index finger proprioception on affected side
- Able to follow 2-step commands (Score of 0 on Item #1c of NIH Stroke Scale).
- English speaking

Exclusion Criteria

- Severe neglect (Score of 2 on Item #11 of NIH Stroke Scale).
- Pain in arm that limits movement or loss of functional range of movement (contracture) limiting participation in the task.
- Inability to maintain independent sitting balance in a standard chair.
- Inability to give informed consent.
- Received a botulinum toxin injection in the UL within past 3 months.

3.3 Baseline Assessments and Outcome Measures

Motor Learning Outcomes

General Set-Up. During the performance of all motor tasks, the participant was seated in a standard chair with feet placed flat on the floor. A seat cushion is provided if needed for the participant's knees to be at a 90-degree angle. Table height was adjusted so that the participant's elbow was at 90 degrees of flexion when the arm was resting on the table with the shoulder in a neutral position. Table height was recorded and kept consistent throughout all visits of the study.

The Scooping Task. The primary outcome of this study was 24-hour retention of the Scooping Task, a functional motor task that participants practiced for two consecutive days. In this task, participants are asked to use a spoon to scoop beans from one cup to another in an anterior-posterior direction. This task has been previously described and tested with individuals with chronic UL hemiparesis after stroke (Schaefer et al., 2013). While formal reliability and validity testing was not completed, as it was not the purpose of the study, the authors

demonstrated that practicing the Scooping Task for five consecutive days (50 trials/day) lead to significant improvements in task performance and also led to significant improvement on an untrained transfer task (see section on the Modified Box and Block test). Two cups placed 16.5cm apart were attached to a board, with the cup closest to the participant filled with 70 beans (See Figure 1). The board was stabilized on the table with Dycem and a weight to prevent sliding. The participant was asked to complete as many scoops of beans as possible within thirty seconds using a spoon with a built-up handle. The number of completed scoops in which at least one bean was transferred was recorded as the score of a trial. Detailed instructions on set-up and administration of the Scooping Task can be found in Appendix A. During the pre-test (Day 1), participants were asked to perform two 30-second trials with their less affected hand and five 30-second trials with their more affected hand. Scores for the five trials performed with the more affected arm were then averaged to determine the score for the block of trials. During the 24-hour retention test (Day 3), participants performed this procedure twice (two blocks). As in the pre-test, scores for the five trials completed with the more affected arm were averaged for each of the two blocks to determine a score for each block.

Figure 1

Scooping Task Set-Up

Note. This image depicts the set-up of the Scooping Task.

Modified Box and Block Test (mBBT). A secondary motor learning outcome was immediate (10-minute) and delayed (24-hour) transfer of an untrained motor task. A modified version of the Box and Block test (mBBT) was used to assess transfer of learning after practice of the Scooping Task. This task was previously studied and was used to demonstrate that practice of the Scooping Task can transfer to improvements on an untrained motor task for individuals with chronic stroke (Schaefer et al., 2013). The mBBT is adapted from the Box and Block test (BBT; Mathiowetz et al., 1985). The BBT is a standardized assessment of manual dexterity that is valid, reliable, and responsive to change for the stroke population (Chen et al., 2009; Lin et al., 2010). In the mBBT, the apparatus for the Box and Block test is turned in an anterior-posterior direction in midline with the participant's body, rather than a mediolateral direction as in the standardized test (See Figure 2). This orientation is similar to the Scooping Task, and both tasks were previously shown to be kinematically similar (Schaefer et al., 2013). During the mBBT, the participant is asked to transfer as many cubes as they can across the partition of the box, away

from their body, within 30 seconds. See Appendix A for detailed instructions on administration of the mBBT. During the pre-test (Day 1), participants were asked to perform two 30-second trials with their less affected hand and five 30-second trials with their more affected hand. During both the immediate (10-minute) transfer test on Day 2 and the delayed (24-hour) transfer test on Day 3, participants were asked to perform two blocks of the same procedure. Similarly to the Scooping Task, scores for each of the five trials completed with the more affected arm within a block were averaged to determine a score.

Figure 2

Modified Box and Block Test (mBBT) Set-Up

Note. This image depicts the set-up of the modified Box and Block Test (mBBT).

Psychological Outcomes

Self-Assessment Manikin (SAM). The valence subscale of the SAM was used to measure positive affect (Bradley & Lang, 1994). This subscale has five pictures of figures with facial expressions that progress from smiling to frowning. Participants select their current mood using a nine-point scale (See Appendix B). Bradley and Lang (1994) found a strong correlation (r = .97) between the valence subscale of the SAM and the pleasure factor of the Semantic

Differential scale, which consists of opposite adjective pairs (e.g., unhappy-happy, annoyed-pleased, etc.) with healthy subjects, demonstrating concurrent validity. Reliability is difficult to demonstrate with this scale because self-reported emotional states are dynamic, but Bradley and Lang (1994) found that scores collected via pen and paper were strongly related to those collected by computer ($r = .99$), demonstrating the stability of the measure (Perse, 2009). Although reliability and validity have not been assessed with the stroke population, Novak and colleagues (2010) found that the valence subscale of the SAM was positively correlated with better performance on a virtual reality UL task for individuals with chronic stroke. Additionally, Wulf and colleagues (2018) used this subscale to measure positive affect in a motor learning study. They found that participants who were allowed to make task-irrelevant choices during motor practice had significantly higher positive affect after the practice phase than those in the yoked control group. They found that this measure also significantly predicted performance on the retention test, which explained 25% of the variance. In the study presented in this dissertation, the valence subscale of the SAM was administered at pre-test (Day 1), post-test (Day 2), and follow-up (Day 3).

Scooping Task Appraisal Scale (STAS). Self-efficacy for performance of the Scooping Task was measured using the Scooping Task Appraisal Scale (See Appendix C). This scale was developed for this study based on Bandura's guide for creating self-efficacy scales (Bandura, 2006). However, one change was made. Bandura's guide suggests having all participants rate their confidence in obtaining the same previously determined scores (e.g. 5, 10, 15, etc.). For this study, it was anticipated that participants would have varying levels of arm impairment, and we did not want self-efficacy scores to be lower for those with lower baseline levels of arm function. Thus, participants were asked to rate their confidence in attaining scores that were related to their

performance during practice. Specifically, participants were given their median score, their maximum score, and a "max-plus" score [(max – median)/2 + max] of all the practice trials that were completed over two days. They were then asked to rate their confidence in attaining each of these scores using a 10-point Likert scale on post-test (Day 2) and follow-up (Day 3). The "max-plus" score was rated to gauge participants' confidence in obtaining a better score than they had in during practice (i.e., to determine if they anticipated that their performance would continue to improve). Participants were not told how these three scores (median, maximum, and max-plus) were related to their performance during practice, but they were told their maximum and minimum scores following each block of trials during the practice phase as well as their overall minimum and maximum scores for each day of practice. This was done so that participants would have a general idea of their performance on the task when rating their self-efficacy.

Intrinsic Motivation Inventory (IMI). The Intrinsic Motivation Inventory measures participants' subjective experience when practicing a task (Ryan, 1982; McAuley et al., 1989). McAuley et al. (1989) investigated the psychometric properties of the IMI in a competitive sports setting using confirmatory factor analysis, and found adequate model fit and reliability. Although formal reliability and validity testing has not been conducted with the stroke population, Verrienti and colleagues (2023) found that the IMI is the most commonly used measure of motivation in stroke rehabilitation interventions. The IMI has six subscales that are each scored independently: interest/enjoyment, perceived competence, perceived choice, pressure/tension, value/usefulness, and effort/importance. The "interest/enjoyment" subscale is the measure of intrinsic motivation. The "perceived competence" and "perceived choice" subscales are thought to be positively related to intrinsic motivation, while the "pressure/tension" subscale is thought to be negatively related to intrinsic motivation (Self-Determination Theory,

n.d.). The "value/usefulness" and "effort/importance" are not measures of intrinsic motivation; rather, these variables are related to extrinsically motivating activities that are autonomous (i.e., motivation that is based on the individual's personal values; Sanli et al., 2013).

The complete IMI includes 45 total items that can be individually selected by the researcher based on the needs of the study (Self-Determination Theory, n.d.). The 28-item instrument used for this study has items from each of the six subscales (interest/enjoyment – 7 items; perceived competence – 5 items; perceived choice – 5 items; pressure/tension – 5 items; value/usefulness – 3 items; effort/importance – 3 items). Twenty-two of the items were taken from a version of the IMI called the Task Evaluation Questionnaire, which uses four of the six subscales (interest/enjoyment, perceived competence, pressure/tension, perceived choice; Self-Determination Theory, n.d.). The remaining six questions were added to represent effort/importance and value/usefulness subscales based on an instrument used by Rowe and colleagues (2017). Responses are rated on a 7-point Likert scale. All items in each subscale are then averaged to determine a score for the subscale. The IMI was administered at the post-test on Day 2 following practice.

Screening and Baseline Characterization Assessments

The following assessments were administered for screening and baseline characterization.

Box and Block Test (BBT). The Box and Block Test (Mathiowetz et al., 1985) is a test of manual dexterity with excellent test-retest reliability for individuals with chronic stroke (Chen et al., 2009). The BBT is responsive to change and has been shown to be a valid measure of UL dexterity for the stroke population (Lin et al., 2010). Participants are asked to transfer as many cubes as they can from one side of a box to the other within one minute using a standardized

apparatus in a mediolateral direction (Mathiowetz et al., 1985). This measure was used for screening and stratification in this study.

Geriatric Depression Scale-Short Form (GDS-SF). The 30-item Geriatric Depression Scale is a valid and reliable screening tool for depression with individuals after stroke (Sivrioglu et al., 2009; Yesavage et al., 1982). This study used the short form of the Geriatric Depression Scale, which is a 15-item depression screening tool with yes/no items. Rasch analysis of the GDS-SF found adequate unidimensionality (Chiang et al., 2009).

Comprehensive Trail-Making Test – Second Edition (CTMT2). CTMT2 is a test of executive function that involves the administration of five trail-making tasks that are intended to measure two different factors: inhibitory control (Trails 1-3) and set-shifting (Trails 4-5) (Reynolds, 2020). CTMT2 is a norm-reference test that was developed based on the original Trail Making Test. Trail 1 resembles Trail A, and Trail 5 resembles Trail B of the original test. Norms for the CTMT2 were developed based on a sample of 1904 individuals living in the United States (Reynolds, 2020). Confirmatory factor analysis was used to demonstrate an excellent fit for the two-factor model with adults (Riccio et al., 2013).

Modified Ashworth Scale (MAS). The MAS is an assessment of spasticity and has been found to have excellent convergent validity with the Fugl-Meyer and the BBT for individuals with chronic stroke (Bohannon & Smith, 1987; F. M. Lin & Sabbahi, 1999).

Sleep Condition Indicator (SCI). The SCI is an 8-item questionnaire designed to screen for sleep disturbance and insomnia with internal consistency and convergent validity (Espie et al., 2014). Although formal reliability and validity testing has not been conducted with the stroke population, the SCI was used to demonstrate that stroke survivors had worse self-reported

insomnia than healthy controls, and poorer SCI scores were also associated with greater depression (Fleming et al., 2021).

3.4 Procedures

Recruitment, Screening, and Baseline Characterization

Participants were recruited from the community through a local stroke research registry, flyers posted in outpatient practices at CUIMC, and referrals from rehabilitation professionals in New York. Individuals who expressed interest in the study were asked pre-screening questions over the phone about their age, date of stroke, ability to move more affected arm (lift arm off the table and reach forward; grasp and release a washcloth with hand), history of UL botulinum toxin injections, and arm pain limiting ability to move. If the pre-screening requirements were met, then an in-person screening session was scheduled. After obtaining written informed consent, participants were screened for inclusion in the study with the following measures: BBT (Mathiowetz et al., 1985), clinical assessment of finger proprioception, and items #1C (following 2-step commands) and #11 (extinction and inattention) on the NIH Stroke Scale (Goldstein et al., 1989). Participants who met inclusion criteria also completed following baseline assessments, which were administered to characterize the sample: GDS (Yesavage et al., 1982); CTMT2 (Riccio et al., 2013); MAS (Bohannon & Smith, 1987); and SCI (Espie et al., 2014).

Randomization and Blinding

Participants were stratified into two groups according to BBT scores (Low: 3-20, High: 21-60). Once two participants were accrued in a stratum, they were paired. Each participant in the pair was then randomized into either experimental or control group by a research team member who was not involved with evaluation or intervention. Research participants were blinded to the overall purpose of the study and were not informed of the difference between the

groups. Participants were debriefed after the completion of study procedures in accordance with IRB policies. Outcome assessors were blinded to group allocation.

Assessment and Training Timeline

After randomization, participants were scheduled to attend in-person research sessions for three consecutive days. This involved a pre-test on Day 1, a practice phase on Days 1 and 2, a post-test on Day 2 following practice, and a follow-up test on Day 3 (See Table 1).

Table 1

Study Procedures for Three Consecutive Days

Day 1	Day 2	Day 3
Pre-Test	Practice Phase	Follow-Up
SAM	Scooping Task Less affected – 20 trials (2 trials x 10 blocks) More affected – 50 trials (5 trials x 10 blocks)	SAM
Scooping Task Less affected (2 trials) More affected (5 trials)		STAS
mBBT Less affected (2 trials) More affected (5 trials)	Post-Test	Scooping Task (RT) *Block 1* Less affected (2 trials) More affected (5 trials) *Block 2* Less affected (2 trials) More affected (5 trials)
Practice Phase	SAM	
Scooping Task Less affected – 20 trials (2 trials x 10 blocks) More affected – 50 trials (5 trials x 10 blocks)	IMI	mBBT (DTT) *Block 1* Less affected (2 trials) More affected (5 trials) *Block 2* Less affected (2 trials) More affected (5 trials)
	STAS	
	mBBT (ITT) *Block 1* Less affected (2 trials) More affected (5 trials) *Block 2* Less affected (2 trials) More affected (5 trials)	

Note. DTT = delayed transfer test. IMI = Intrinsic Motivation Inventory. ITT = immediate transfer test. mBBT = modified Box and Block Test. RT = retention test. SAM = Self-Assessment Manikin (valence subscale). STAS = Scooping Task Appraisal Scale.

Data Collection

Outcomes were collected at three time points: pre-test (Day 1), post-test (Day 2), and follow-up (Day 3). Outcomes were evaluated by two trained assessors who were blinded to group allocation. Both assessors demonstrated proficiency in administering the assessments, and inter-rater reliability with assessment administration was confirmed. See Appendix A for the Blinded Assessor Manual.

Retention Test (24-Hour). The primary outcome of this study was retention of the Scooping Task. Performance of the Scooping Task was assessed on Day 1 before practice (pre-test) and on Day 3 (24-hour retention test).

Immediate (10-Minute) and Delayed (24-Hour) Transfer of Learning. The mBBT was used to measure transfer of learning on an untrained task. Performance on the mBBT was assessed on Day 1 before practice (Pre-Test). Immediate (10-minute) transfer of learning was assessed on Day 2 after the completion of the practice phase. Delayed (24-hour) transfer of learning was assessed on Day 3.

Psychological Assessments. Participants rated their mood on Day 1 before practice, on Day 2 after practice, and on Day 3 before completing the motor assessments using the valence subscale of the SAM. The STAS was administered on Day 2 after practice and on Day 3 before completing the motor assessments. The IMI is administered on Day 2 following completion of practice.

Practice Phase

Following the pre-test on Day 1, participants in both groups practiced the Scooping Task for two consecutive days. Each day, participants completed 50 trials (10 blocks of 5 trials) with their more affected arm and 20 trials (10 blocks of 2 trials) with their less affected arm. Each trial was 30-seconds. The number of successful repetitions within 30 seconds was counted. During practice, twenty cards (10 yellow, 10 blue) were laid on the table to represent each of the practice blocks. Yellow cards represented a block of trials with the more affected limb, while blue cards represented a block of trials with the less affected limb (See Figure 3).

Experimental Versus Control Groups. Each participant in the control group was paired with a participant in the experimental group. Participants in the experimental group chose the

order they practiced blocks of trials by selecting either a yellow card or a blue card before each block until all twenty blocks were completed. The control group performed the same number of blocks but were not given a choice in the order that they practiced the blocks. Rather, the researcher selected the card based on a pre-determined order that was selected by their counterpart in the experimental group. Participants in the control group were yoked to the choices made by the experimental group in order to control for the variation in order among experimental group participants. See Appendix E for the Intervention Script.

Figure 3

Practice Phase Set-Up

Note. This image depicts the set-up of the Scooping Task during the practice phase. Yellow cards represent blocks of trials performed with the more affected arm, and blue cards represent block of trials performed with the less affected arm.

3.5 Data Analysis

Data were analyzed with IBM SPSS Statistics 28. Descriptive statistics were calculated for all data. Demographic and baseline clinical characteristics were analyzed to determine if

there are baseline imbalances between groups. The Shapiro-Wilk test of normality found that data from motor learning outcomes (Scooping Task and mBBT) were not normally distributed ($p < .05$). Therefore, nonparametric statistical analysis was used. Within group changes on performance of the Scooping Task and mBBT were calculated using the Wilcoxon signed-rank test. Pre-test scores were compared with Block 1 and Block 2 of the retention test, the immediate transfer test, and the delayed transfer test to determine if there were significant changes on the outcomes for each group. Between-group differences in change from the pre-test to each block of the retention, immediate transfer, and delayed transfer tests were also calculated using the Wilcoxon signed-rank test. The Wilcoxon signed-rank test was selected to analyze between-group differences to account for the matched pairs, as both participants within a pair completed the same practice schedule. The Wilcoxon signed-rank test was also used to determine between-group differences on the Self-Assessment Manikin, Scooping Task Appraisal Scale, and each subscale of the Intrinsic Motivation Inventory. Effect sizes for non-parametric data were calculated using Pearson's r ($r = Z/\sqrt{N}$). Effect sizes based on Pearson's r were interpreted based on Cohen's (1992) definitions: small (0.10), medium (0.30), and large (0.50). Associations between change in motor learning outcomes and psychological variables were also explored using Spearman's rank-order correlation, and significant correlations were reported. Significant correlations were interpreted based on the "rule of thumb" described by Prion and Haerling (2014): negligible (0 to ±0.20); weak (±0.21 to ±0.40); moderate (±0.41 to ±0.60); strong (±0.61 to ±0.80); and very strong (±0.81 to ±1.00). Associations between baseline measures (Scooping Task, mBBT, and SAM), and IMI subscales were also explored. Significance level was set at 0.05 (2-sided) for all statistical tests.

Chapter 4: Results

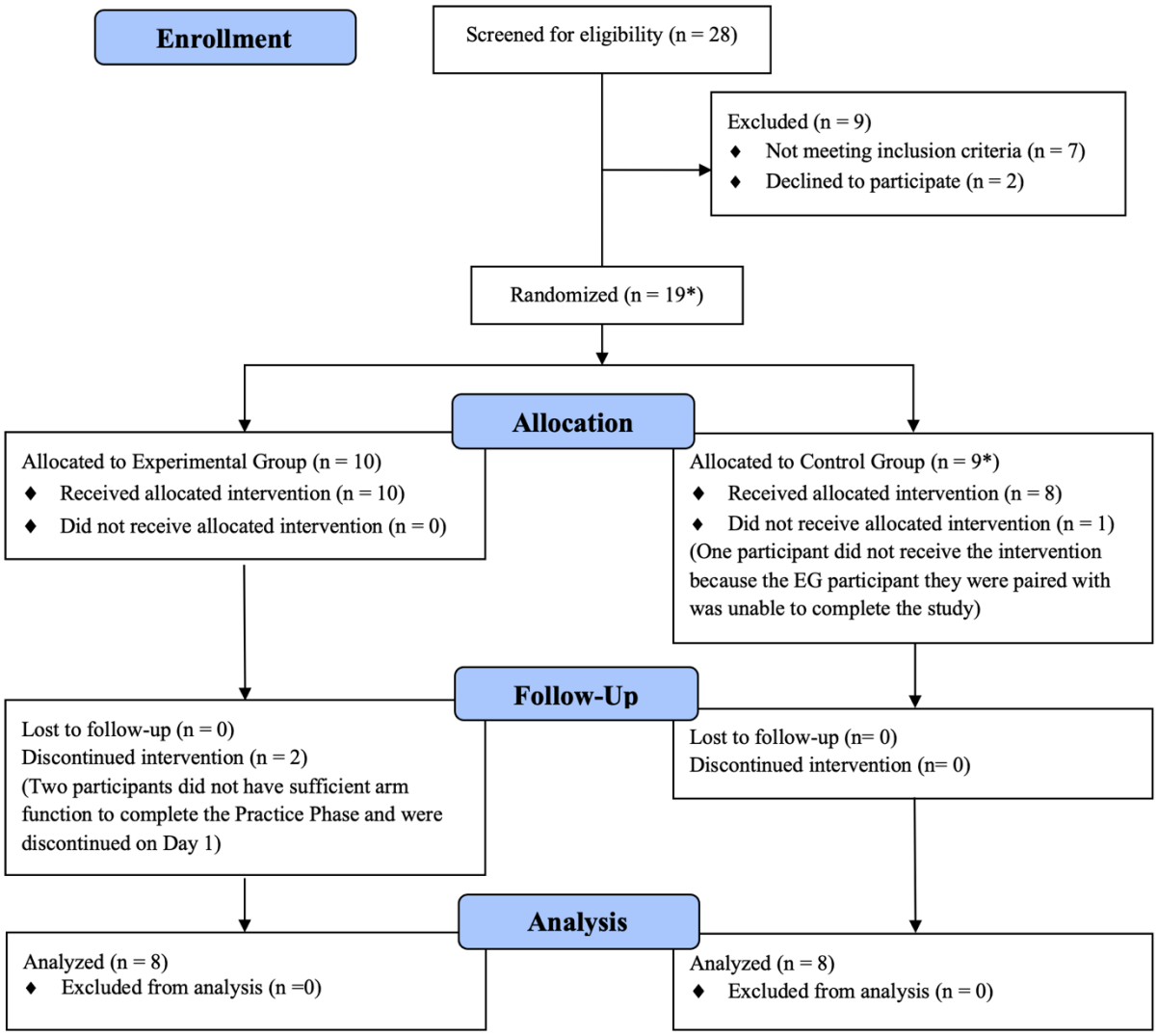
A Consort Flow Diagram can be found in Figure 4. Twenty-eight individuals were screened for inclusion in the study. Of these individuals, seven did not meet inclusion criteria and two declined to participate following the screening visit. Nineteen individuals were included in the study. Three of these participants did not complete study procedures. Two participants were unable to complete the practice phase of the study due to insufficient arm function. One of these participants was randomized to the EG, and their partner (who was originally randomized to the CG) was then re-paired and was re-randomized to the EG to be able to participate in the study. When this participant was also unable to complete the study due to insufficient arm function, the participant they were paired with in the CG was unable to receive the intervention due to lack of a partner.

4.1 Participant Characteristics

A total of sixteen participants completed the study (EG, n=8; CG, n=8) and were included in the analysis. Sample characteristics can be found in Table 2. The only significant difference between groups was elbow flexor spasticity measured with the Modified Ashworth Scale (p <.001). The EG had significantly greater baseline elbow flexor spasticity (*Median* = 1+) than the CG (*Median* = 1). However, baseline elbow flexor spasticity was not significantly correlated with change on any of the motor learning outcome measures (p > 0.05). The EG included only one female and seven males, while the CG was evenly balanced between genders (4 females, 4 males). Both groups included participants from different racial and ethnic backgrounds and were evenly balanced for type of stroke and hand dominance. In the EG, 3 participants were right hand-affected, while 5 were left arm-affected; in the CG, 4 participants were right arm-affected, while 4 were left arm-affected.

Figure 4

Consort Flow Diagram



Note. Consort flow diagram. *One participant was initially randomized to the control group (CG), but the matched participant in the experimental group (EG) was unable to complete the intervention. They were then re-paired and randomized to the EG. The numbers shown reflect this second allocation to the EG. This participant was also unable to complete the study, so the participant they were re-paired with in the CG did not receive the intervention.

Table 2

Baseline Sample Characteristics

Baseline Characteristic	EG (n=8)	CG (n=8)	*p*-value
Age in years, mean (SD)	54.50 (6.09)	57.63 (9.50)	.449[a]
Gender	1 Female 7 Male	4 Female 4 Male	.282[b]
Race/Ethnicity	1 Black 1 Black/Hispanic 4 White 2 Undisclosed	1 Asian 2 Black 3 White 2 Multiple/Hispanic	N/A
Months post-stroke, mean (SD)	146.13 (165.39)	135.88 (78.06)	.877[a]
Stroke type	7 Ischemic 1 Hemorrhagic	7 Ischemic 1 Hemorrhagic	1.00[b]
Affected arm	3 Right 5 Left	4 Right 4 Left	1.00[b]
Hand dominance	7 Right 1 Left	7 Right 1 Left	1.00[b]
BBT Score (more affected), mean (SD)	29.25 (11.11)	28.50 (12.98)	.903[a]
SCI Score, mean (SD)	23.50 (7.21)	23.50 (9.34)	1.00[a]
GDS Score, mean (SD)	3.13 (3.04)	3.38 (2.50)	.860[a]
CTMT2 ICI T-Score, mean (SD)	40.00 (12.22)	36.63 (15.59)	.638[a]
CTMT2 SSI T-Score, mean (SD)	40.50 (13.90)	31.63 (11.81)	.191[a]
CTMT2 TCI T-Score, mean (SD)	39.75 (12.49)	34.5 (13.65)	.436[a]
MAS (elbow flexors), median (SD)	1+ (0.54)	1 (0.52)	<.001[c]

Note. SD = standard deviation. *P*-values are 2-sided significance of between group comparisons using a) Welch's t-test or b) Fisher's exact test or c) Mann-Whitney U test. BBT = Box and Block Test. SCI = Sleep Condition Indicator. GDS = Geriatric Depression Scale. CTMT2 = Comprehensive Trail Making Test, Second Edition. ICI = Inhibitory Control Index. SSI = Set-Shifting Index. TCI = Total Composite Index. MAS = Modified Ashworth Scale.

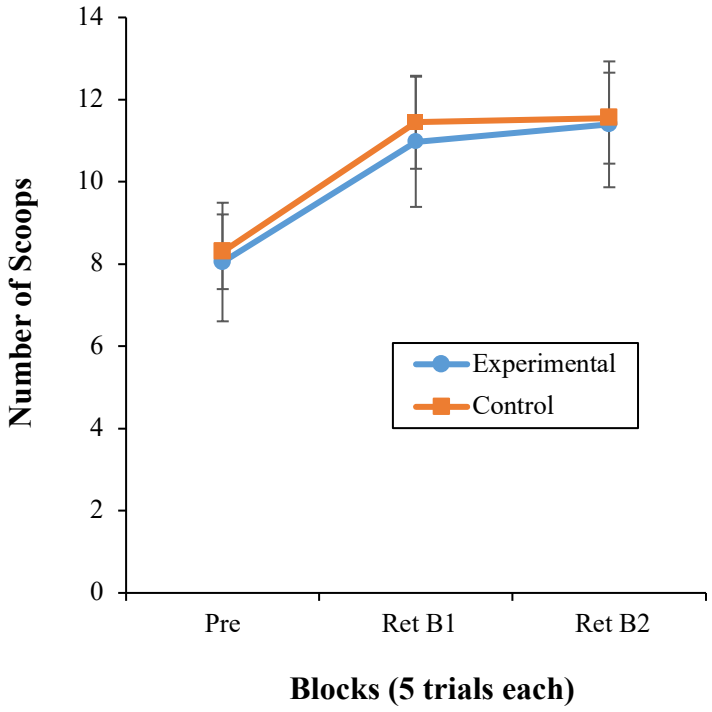
4.2 Motor Learning Outcomes

Primary Outcome (Scooping Task)

The Scooping Task was administered on Day 1 (1 block of 5 trials) and on Day 3 (2 blocks of 5 trials) to measure 24-hour retention of the trained task for the more affected arm. Each block of 5 trials was averaged to determine a score. Each group's performance on the Scooping Task can be seen in Figure 5.

Figure 5

Group Performance on 24-Hour Retention of the Scooping Task



Note. This figure demonstrates group performance on the Scooping Task with the more affected arm at the pre-test (Day 1) and both blocks of the 24-hour retention test (Day 3). Each block of 5 trials was averaged to get a score. Group means are shown with error bars indicating the standard error. Pre = Day 1 pre-test; Ret = Day 3 24-hour retention test; B1 = Block 1; B2 = Block 2.

Within-Group Changes. Within-group changes between the pre-test and each block of the retention test were calculated for each group. Both groups demonstrated significant improvements, and all eight participants in both the EG ad CG increased the number of completed scoops from pre-test to Block 1 and Block 2 of the retention test (see Table 3). For the EG, there was a median increase of 2.7 scoops from the pre-test (*Median* = 8.9) to Block 1 of the retention test (*Median* = 11.6), z = 2.54, *p* = .011, as well as a median increase of 3.5 scoops from the pre-test (*Median* = 8.9) to Block 2 of the retention test (*Median* = 12.6), z = 2.52, *p* = .012. The CG demonstrated a median increase of 3.5 scoops from the pre-test (*Median* = 7.7) to Block 1 of the retention test (*Median* = 9.9), z = 2.52, *p* = .012, as well as a median increase of 3.2 scoops from the pre-test (*Median* = 7.7) to Block 2 of the retention test (*Median* = 10.6), z = 2.52, *p* = .012.

Within-group changes between Block 1 and Block 2 of the retention test were also calculated. Six participants in the EG increased the number of completed scoops between blocks while two participants completed fewer; there was no significant increase in number of scoops (Median = .5), z = 1.56, p = .120. In the CG, three participants completed more scoops at Block 2, while five participants completed fewer scoops; there was no significant increase in number of scoops (Median = -.2), z = -.07, p = .943.

Between-Group Differences. Differences between groups in change in number of scoops from pre-test to Block 1 and Block 2 of the retention test were also calculated (see Table 3). There was no difference in change from the pre-test to Block 1 of the retention test (*Median* = -.8 scoops) between the EG (*Median* = 2.7 scoops) and CG (*Median* = 3.5 scoops), z = -.70, *p* = .483. For five pairs, the CG participant had more improvement, while for three pairs, the EG participant had more improvement. There was also no difference in change from the pre-test to

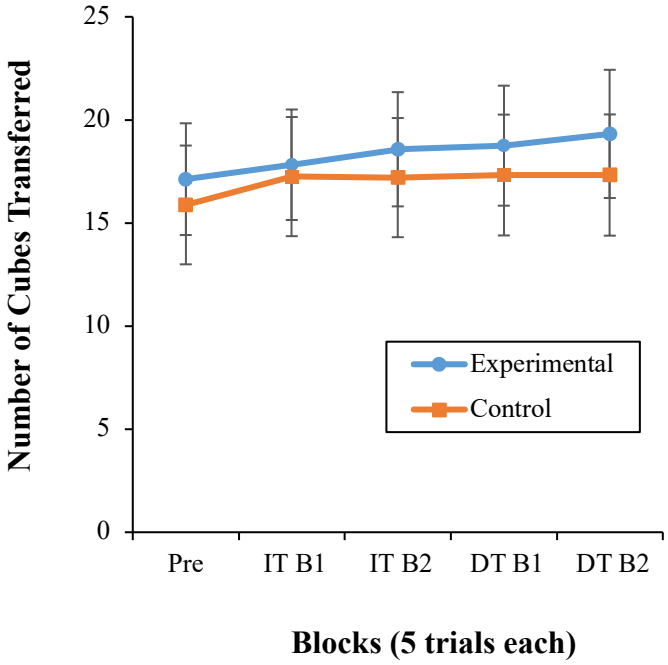
Block 2 of the retention test (*Median* = .2 scoops) between EG (*Median* = 3.5 scoops) and CG (*Median* = 3.2 scoops), z = .70, *p* = .482. For six pairs, the EG participant had greater improvement, while for two pairs, the CG participant improved more. There were no differences between EG and CG on change between Blocks 1 and 2 of the retention test, z = .63, p = .528; in four pairs, the EG participants completed more scoops, while in the other four pairs, the CG participant completed more scoops.

Secondary Outcome (mBBT)

Immediate (10-minute) and delayed (24-hour) transfer of learning to an untrained task were measured using the mBBT. The mBBT was administered on Day 1 (pre-test; 1 block of 5 trials), Day 2 (immediate transfer test; 2 blocks of 5 trials), and Day 3 (delayed transfer test; 2 blocks of 5 trials). Each block of 5 trials was averaged to determine a score. Each group's performance on the mBBT can be seen in Figure 6.

Figure 6

Group Performance on Immediate and Delayed Transfer of Learning Tests



Note. This figure shows group performance on the modified Box and Block Test with the more affected arm at the pre-test, the Day 2 immediate (10-minute) transfer test, and the Day 3 delayed (24-hour) transfer test. Each block of 5 trials was averaged to determine a score. Group means are shown with error bars indicating the standard error. Pre = pre-test; IT = immediate transfer test; DT = delayed transfer test; B1 = block 1; B2 = block 2.

Within-Group Changes. Within-group changes between the pre-test and each block of the immediate and delayed transfer tests were calculated for each group (see Table 3).

Immediate Transfer Test. For the immediate transfer test on Day 2 following practice, the EG did not demonstrate significant improvement in number of transferred cubes (*Median* = 0.70) from the pre-test (*Median* = 21.0) to Block 1 (*Median* = 21.0), z = 1.183, *p* = .237; five participants in the EG increased the number of transferred cubes, two transferred fewer cubes,

and one did not change. However, there was a significant median improvement in number of transferred cubes (*Median* = 1.5) from the pre-test (*Median* = 21.0) to Block 2 of the immediate transfer test (*Median* = 22.2), z = 2.03, *p* = .043; six participants increased the number of transferred cubes, one transferred fewer cubes, and one did not change. The CG demonstrated significant improvement from pre-test to both Block 1 and Block 2 of the immediate transfer test. There was a significant median change in number of transferred cubes (*Median* = 1.2) from the pre-test (*Median* = 15.3) to Block 1 (*Median* = 15.9), z = 2.20, *p* = .028; six participants in the CG increased the number of transferred cubes, one transferred fewer cubes, and one did not change. For the second block of trials, there was also a significant median increase in number of transferred cubes (*Median* = 1.1) from the pre-test (*Median* = 15.3) to Block 2 (*Median* = 16.2), z = 2.53, *p* = .012, and all eight participants in the CG improved from their scores on the pre-test.

Within-group changes between Block 1 and Block 2 of the immediate transfer test were also calculated. Seven participants in the EG transferred more cubes at Block 2 while one participant completed fewer; there was a significant median increase in number of transferred cubes between Blocks 1 and 2 (Median = .6), z = 1.97, p = .049. In the CG, three participants transferred more cubes at Block 2, four participants transferred fewer cubes, and one transferred the same number of cubes. There was no significant difference between blocks (Median = -.1), z = -.26, p = .798.

Delayed Transfer Test. For the delayed transfer test on Day 3, both the EG and the CG significantly improved at both Blocks 1 and 2 from the pre-test. For the EG, there was a significant change in number of transferred cubes (*Median* = 1.9) from the pre-test (*Median* = 21.0) to Block 1 of the delayed transfer test (*Median* = 22.7), z = 2.12, *p* = .034; six participants in the EG increased the number of transferred cubes, one transferred fewer cubes, and one did

not change. There was also a significant change in number of transferred cubes (*Median* = 1.5) from the pre-test (*Median* = 21.0) to Block 2 (*Median* = 22.9), z = 2.38, *p* = .017; seven participants increased the number of transferred cubes, and one transferred fewer cubes. For the CG, all eight participants improved from the pre-test to both Block 1 and Block 2. There was a significant increase in number of scoops (*Median* = 1.4) from the pre-test (*Median* = 15.3) to Block 1 (*Median* = 16.1), z = 2.52, *p* = .012, and from the pre-test to Block 2 (*Median* = 16.1), z = 2.52, *p* = .012.

Within-group changes between Block 1 and Block 2 of the delayed transfer test were also calculated. Five participants in the EG transferred more cubes at Block 2 while three participants transferred fewer cubes; overall, there was no significant increase in number of transferred cubes between Blocks 1 and 2 (Median = .6), z = 1.40, p = .161. In the CG, four participants transferred more cubes at Block 2, and four participants transferred fewer cubes. There also was no significant difference between blocks (Median = 0.0), z = 0.00, p = 1.000.

Between-Group Differences. Differences between groups in change in number of transferred cubes from pre-test to Block 1 and Block 2 of the immediate transfer test and the delayed transfer test were also calculated (see Table 3).

Immediate Transfer Test. There was no significant difference in change from the pre-test to Block 1 of the immediate transfer test (*Median* = -1.2 cubes) between EG (*Median* = .7 cubes) and CG (*Median* = 1.2 cubes), z = -.98, *p* = .327. For three pairs, the EG participant had more improvement, while for five pairs, the CG participant had more improvement. There was also no difference in change from pre-test to Block 2 (*Median* = -.4 cubes) between EG (*Median* = 1.5 cubes) and CG (*Median* = 1.1 cubes), z = .56, *p* = .574; for four pairs, the EG participant had more improvement, while for four pairs, the CG participant had more improvement. There was a

significant difference between the EG and the CG on change between Blocks 1 and 2, z = 2.32, *p* = .021; for seven pairs, the EG participant improved more, while for one pair, the CG participant improved more.

Delayed Transfer Test. There was also no significant difference in change from the pre-test to Block 1 of the delayed transfer test (*Median* = .3 cubes) between EG (*Median* = 1.9 cubes) and CG (*Median* = 1.4 cubes), z = .14, *p* = .889. The EG participant improved more in four of the pairs, while the CG participant improved more in four pairs. Similarly, there was also no difference in change from pre-test to Block 2 (*Median* = .6 cubes) between EG (*Median* = 1.5 cubes) and CG (*Median* = 1.4 cubes), z = .70, *p* = .482; the EG participant improved more in five of the pairs, while the CG participant improved more in three pairs. There was also no significant difference between the EG and the CG on change between Blocks 1 and 2, z = 1.27, *p* = .205; for five pairs, the EG participant improved more, while for three pairs, the CG participant improved more.

Table 3

Motor Learning Outcome Results

	Within-group changes Mean (SD) – Median [95% CI for the mean]							Between-group differences *p*-values, Pearson's *r*	
	Pre-test	Post-test B1	Change from pre-test to B1	*p*-values	Post-test B2	Change from pre-test to B2	*p*-values	Change from pre-test to B1	Change from pre-test to B2
Retention Test (Scooping Task)									
EG	8.05 (4.08) – 8.9 [4.64, 11.46]	10.98 (4.48) – 11.6 [7.22, 14.72]	2.93 (1.47) – 2.7 [1.69, 4.16]	**.011**	11.40 (4.33) – 12.6 [7.77, 15.02]	3.35 (1.26) – 3.5 [2.29, 4.41]	**.012**	p = .483, r = -.247	p = .482, r = .247
CG	8.30 (2.57) – 7.7 [6.15, 10.45]	11.45 (3.20) – 9.9 [8.77, 14.13]	3.15 (1.22) – 3.5 [2.13, 4.17]	**.012**	11.55 (3.13) – 10.6 [8.94, 14.16]	3.25 (1.44) – 3.2 [2.05, 4.45]	**.012**		
Immediate Transfer Test (mBBT)									
EG	17.13 (7.66) – 21.0 [10.72, 23.53]	17.83 (7.58) – 21.0 [11.48, 24.16]	0.70 (1.72) – 0.70 [-.74, 2.14]	.237	18.8 (7.86) – 22.2 [12.01, 25.14]	1.45 (1.49) – 1.5 [0.20, 2.70]	**.043**	p = .327, r = -.346	p = .574, r = .198
CG	15.88 (8.14) – 15.3 [9.07, 22.68]	17.25 (8.17) – 15.9 [10.42, 24.08]	1.38 (1.19) – 1.2 [0.37, 2.37]	**.028**	17.20 (8.17) – 16.2 [10.37, 24.3]	1.33 (0.73) – 1.1 [.71, 1.94]	**.012**		
Delayed Transfer Test (mBBT)									
EG	(See immediate transfer test above for mBBT pre-test score*)	18.75 (8.24) – 22.7 [11.86, 25.64]	1.63 (1.51) – 1.9 [0.36, 2.89]	**.034**	19.33 (8.82) – 22.9 [11.95, 28.70]	2.20 (2.20) – 1.5 [0.36, 4.04]	**.017**	p = .889, r = .049	p = .482, r = .247
CG		17.33 (8.28) – 16.1 [10.40, 24.25]	1.45 (0.78) – 1.4 [0.80, 2.10]	**.012**	17.33 (8.30) – 16.1 [10.38, 24.27]	1.45 (0.92) – 1.4 [0.68, 2.22]	**.012**		

Note: N = 16 (EG, *n* = 8; CG, *n* = 8). Wilcoxon signed-rank tests were used to determine within-group changes for each group from pre-test to Block 1 and 2 of the retention test, immediate transfer test, and delayed transfer test. The Scooping Task was used to assess 24-hour retention on Day 3, and the modified Box and Block Test (mBBT) was used to assess immediate transfer on Day 2 and delayed transfer on Day 3. Wilcoxon signed-rank tests were also used to determine between-group differences for each block of trials. Significant *p*-values (2-sided) are in bold ($p < .05$). Effect sizes for between-group differences were calculated using Pearson's r ($r = Z/\sqrt{N}$). SD = standard deviation; B1 = Block 1; B2 = Block 2; EG = experimental group; CG = control group; mBBT = modified Box and Block Test. *Both the immediate and delayed transfer tests used the mBBT. The mBBT pre-test is shown in the immediate transfer test section of the table.

4.3 Psychological Outcomes

Positive Affect

The valence subscale of the Self-Assessment Manikin Scale was used to measure positive affect at the Day 1 pre-test, Day 2 post-test, and Day 3 follow-up. Lower scores indicate more positive affect. No significant differences were found between groups on rating of positive affect at the Day 1 pre-test, Day 2 post-test, or Day 3 follow-up (see Table 4). At the pre-test, the EG participant had more positive affect in three of the pairs, while the CG participant had more positive affect in five of the pairs. A median baseline difference of 1.0 between the groups was not significant. Similarly, at the post-test on Day 2, the EG participant had more positive affect in three pairs, the CG participant had more positive affect in four pairs, and one pair had the same rating of affect with a median difference of 0.5. At Day 3, the median difference between groups was 0.0. In two pairs, the EG participant had more positive affect, in two pairs the CG participant had more positive affect, and four pairs had the same rating of affect.

In the EG, there was a non-significant trend towards increased positive affect from the Day 1 pre-test to the Day 2 post-test, $z = 1.73$, $p = .083$; three participants increased in positive affect while five did not change. In the CG, this trend was not seen, $z = -.56$, $p = .577$; one participant had more positive affect, three had more negative affect, and four did not change. There was no difference between groups on change in mood from the Day 1 pre-test to the Day 2 post-test, $z = 1.09$, $p = .276$; in four pairs, the EG participant had increased positive affect, in one pair, the CG participant had increase positive affect, and three pairs had no change in affect. A moderate effect size favored the EG, $r = .385$. See Figure 7 for box plots of results.

Table 4

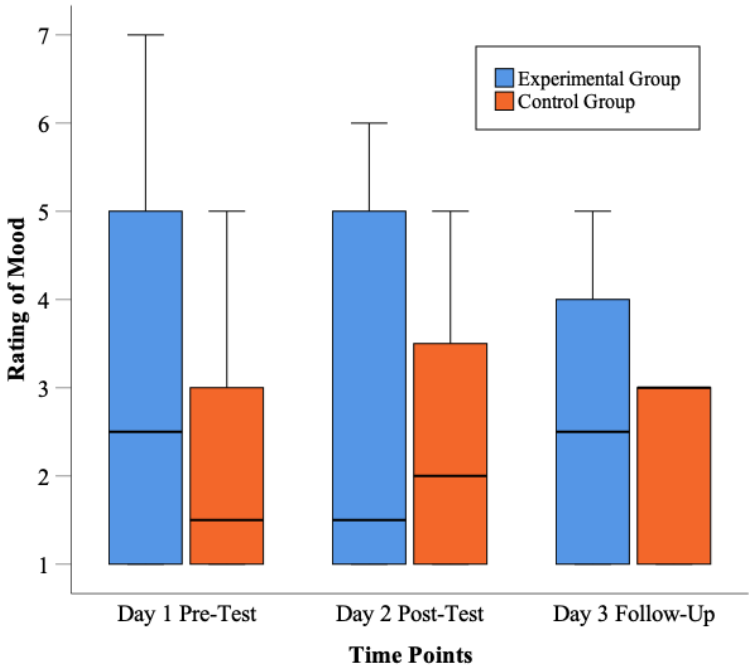
Self-Assessment Manikin Results

SAM	EG (n=8)	CG (n=8)	Z	Pearson's r	*p*
Day 1 Pre-Test	2.5 (4)	1.5 (2)	0.95	.336	.343
Day 2 Post-Test	1.5 (4)	2.0 (3)	0.34	.120	.732
Day 3 Follow-Up	2.5 (4)	3.0 (2)	0.55	.194	.581

Note. Group medians (interquartile range) are reported for each rating. Lower scores indicate more positive affect. Wilcoxon signed rank tests were used to determine differences between groups. Z-scores, Pearson's r (effect sizes), and *p*-values (2-sided) are reported. The Self-Assessment Manikin can be found in Appendix B. EG = experimental group; CG = control group; SAM = Self-Assessment Manikin.

Figure 7

Box Plots of Ratings of Mood on the Self-Assessment Manikin Scale



Note. Box plots are shown for each rating of mood on the Self-Assessment Manikin scale at Day 1, Day 2, and Day 3. Lower scores indicate more positive affect.

Self-Efficacy

Self-efficacy was measured using the Scooping Task Appraisal Scale (STAS) at the Day 2 post-test and the Day 3 follow-up. Participants rated their confidence in attaining their median, maximum, and max-plus [(max – median)/2 + max] scores from the practice phase. No differences were found between groups on any of the self-efficacy ratings (see Table 5). Box plots of confidence ratings can be found in Figure 8.

Day 2 Self-Efficacy. There was no difference (*Median* = .5) on self-efficacy ratings for the median score of the Scooping Task. The EG participant had higher self-efficacy in four pairs, the CG participant had higher self-efficacy in two pairs, and two pairs had the same self-efficacy rating. Additionally, the median differences between groups on the max (*Median* = -1.5) and max-plus (*Median* = .5) self-efficacy scores were also not significant. For the max self-efficacy rating, the EG participant had higher self-efficacy in three pairs, while the CG participant had higher self-efficacy in five pairs. For the max-plus rating, the EG participant had higher self-efficacy in four pairs, and the CG participant had higher self-efficacy in four pairs.

Day 3 Self-Efficacy. At Day 3, the differences between groups were not significant for the median (*Median* = 0.0), max (*Median* = -.5), or max plus (*Median* = .5) self-efficacy ratings. For the median self-efficacy rating, the EG participant had higher self-efficacy in three pairs, the CG participant had higher self-efficacy in three pairs, and two pairs had the same self-efficacy rating. For the max self-efficacy rating, the EG participant had higher self-efficacy in three pairs, the CG participant had higher self-efficacy in four pairs, and one pair had the same self-efficacy rating. For the max-plus self-efficacy rating, the EG participant had higher self-efficacy in four pairs, the CG participant had higher self-efficacy in three pairs, and one pair had the same self-efficacy rating.

Table 5

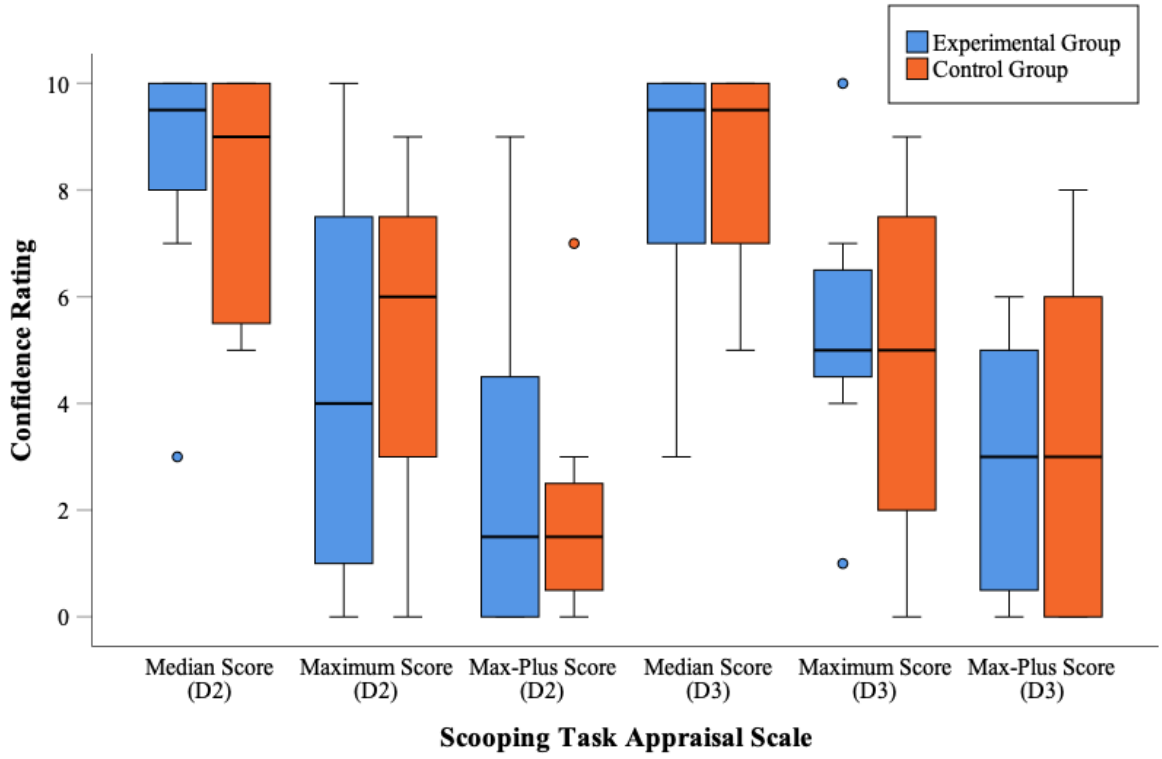
Scooping Task Appraisal Scale Results

STAS	EG (n=8)	CG (n=8)	Z	Pearson's r	*p*
Day 2					
Median Score	9.5 (3)	9.0 (5)	0.53	.187	.595
Max Score	4.0 (7)	6.0 (5)	-0.63	-.223	.526
Max-Plus Score	1.5 (5)	1.5 (3)	0.42	.148	.673
Day 3					
Median Score	9.5 (4)	9.5 (4)	-0.11	-.039	.916
Max Score	5.0 (3)	5.0 (6)	0.25	.088	.799
Max-Plus Score	3.0 (5)	3.0 (7)	-0.17	-.060	.865

Note. Group medians (interquartile range) are reported for each rating. Wilcoxon signed rank tests were used to determine differences between groups. Z-scores, Pearson's r (effect sizes), and p-values (2-sided) are reported. The Scooping Task Appraisal Scale can be found in Appendix C. Participants were asked to rate their confidence for obtaining their median score, maximum score, and max-plus score [(max – median)/2 + max] on the Scooping Task after two days of practice. Higher scores indicate higher self-efficacy. EG = experimental group; CG = control group; STAS = Scooping Task Appraisal Scale.

Figure 8

Box Plots of Confidence Ratings on the Scooping Task Appraisal Scale



Note. Box plots are shown for each confidence rating on the Scooping Task Appraisal Scale at Day 2 and Day 3. Participants rated their confidence for obtaining their median score, maximum score, and max-plus score [(max – median)/2 + max] on the Scooping Task after two days of practice. Higher scores indicate greater confidence in achieving the given score on the Scooping Task (self-efficacy). D2 = Day 2; D3 = Day 3.

Intrinsic Motivation Inventory

Six subscales of the Intrinsic Motivation Inventory (IMI) were administered on Day 2 following the practice phase to measure intrinsic motivation and related constructs. Items from each subscale were averaged to determine a score. No significant differences were found

between groups on any of the IMI subscales (see Table 6). Box plots of IMI subscales can be found in Figure 9.

Interest/Enjoyment. On the "interest/enjoyment" subscale of the IMI, four pairs in the EG rated higher interest/enjoyment of the Scooping Task, while four pairs in the CG rated higher interest/enjoyment. There was no significant difference (*Median* = -.29) between groups on interest and enjoyment.

Perceived Competence. Similarly, the EG participant in four of the pairs rated higher perceived competence of the Scooping Task, while the CG participant in four pairs rated higher perceived competence. There was no significant difference (*Median* = -.40) between groups on rating of interest and enjoyment.

Perceived Choice. For four pairs, the EG participant had a higher rating for choice, and for 3 pairs, the CG participant had a higher rating for choice. One pair had the same rating. There was no significant difference (*Median* = .2) between groups on the perceived choice rating.

Pressure/Tension. The EG participant had a higher rating for pressure/tension in three pairs, while in four of the pairs, the CG participant had a higher rating for pressure/tension. One pair had the same rating for pressure/tension. There was no difference (*Median* = -.1) between groups on rating of pressure and tension.

Value/Usefulness. The EG participant had a higher rating of value/usefulness in three pairs, while the CG participant had a higher rating of value/usefulness in four pairs. One pair had the same rating. There was no significant difference (*Median* = -.5) between groups on rating of value and usefulness.

Effort/Importance. The EG participant had a higher rating of effort/importance in two pairs, while the CG participant had a higher rating of effort/importance in five pairs. One pair

had the same rating. There was no significant difference (*Median* = -.67) between groups on rating of value and usefulness.

Table 6

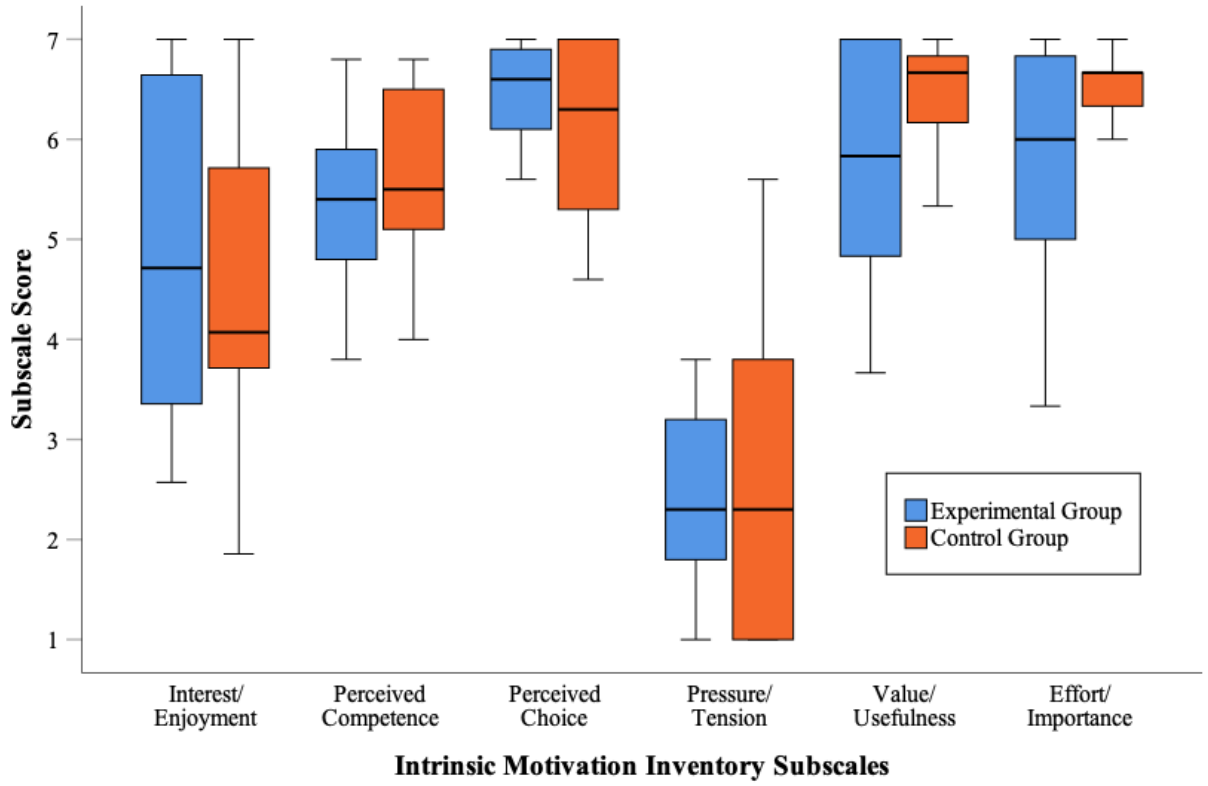
Intrinsic Motivation Inventory Results

IMI Subscales	EG (n=8)	CG (n=8)	Z	Pearson's r	*p*
Interest/Enjoyment	4.71 (3.79)	4.07 (2.07)	0.35	.124	.726
Perceived Competence	5.40 (1.50)	5.50 (1.35)	-0.78	-.276	.435
Perceived Choice	6.60 (1.00)	6.30 (1.95)	1.10	.389	.271
Pressure/Tension	2.30 (1.60)	2.30 (3.20)	0.10	.035	.799
Value/Usefulness	5.83 (2.58)	6.67 (0.83)	-1.01	-.357	.310
Effort/Importance	6.00 (1.92)	6.67 (0.33)	-1.60	-.566	.108

Note. Group medians (interquartile range) are reported for each subscale. Wilcoxon signed rank tests were used to determine differences between groups. Z-scores, Pearson's r (effect sizes), and *p*-values (2-sided) are reported. The Intrinsic Motivation Inventory can be found in Appendix D. Higher scores indicate a greater degree of the construct being measured. For example, higher scores in Interest/ Enjoyment indicate greater interest and enjoyment (intrinsic motivation). Higher scores in Pressure/ Tension indicate more pressure and tension. EG = experimental group; CG = control group; IMI = Intrinsic Motivation Inventory.

Figure 9

Box Plots of Intrinsic Motivation Inventory Subscales



Note. Box plots are shown for subscale of the Intrinsic Motivation Inventory at Day 2. Higher scores indicate a greater degree of the construct being measured. For example, higher scores in Interest/ Enjoyment indicate greater interest and enjoyment (intrinsic motivation). Higher scores in Pressure/ Tension indicate more pressure and tension.

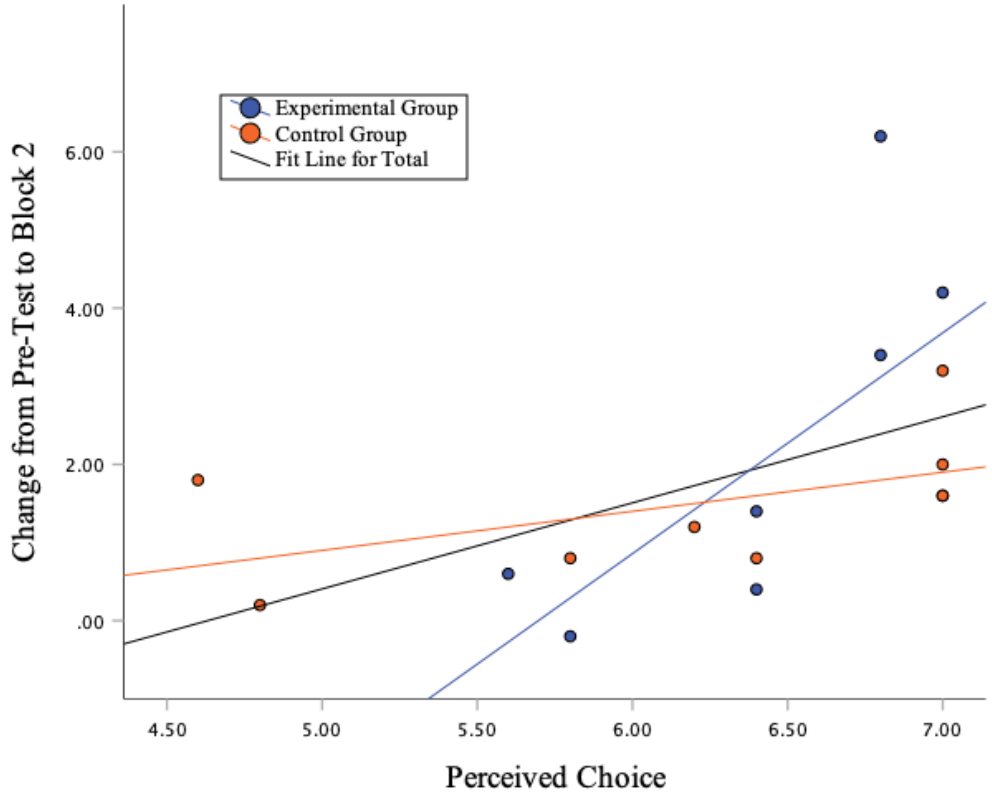
4.4 Correlations Between Motor Learning and Psychological Outcomes

Associations between change on motor learning outcomes and psychological variables were also explored. Spearman's rank-order correlations were run to assess the relationship between change from pre-test to each block of the retention, immediate transfer, and delayed transfer tests and each of the psychological variables (positive affect, self-efficacy, and IMI subscales) within the sample of 16 participants. The "perceived choice" subscale of the IMI was

the only psychological variable that was significantly correlated with change in a motor learning outcome. Visual inspection of scatterplots revealed that there was a monotonic relationship between the "perceived choice" subscale and both the first and second blocks of the delayed transfer test. Higher perceived choice was moderately associated with more improvement on the delayed transfer test at Block 1, r_s (14) = .518, p = .040, 95% CI [.014, .812], and was strongly associated with more improvement at Block 2, r_s (14) = .647, p = .007, 95% CI [.207, .869]. Further exploration of subgroups found that, within the EG, there was a strong correlation between perceived choice and improvement on the delayed transfer test, which approached significance at Block 1, r_s (6) = .703, p = .052, 95% CI [-.029, .944], and was statistically significant at Block 2, r_s (6) = .752, p = .032, 95% CI [.074, .954]. Within the CG, there was no statistically significant relationship between perceived choice and improvement on the delayed transfer test at either Block 1, r_s (6) = .268, p = .520, 95% CI [-.556, .827], or Block 2, r_s (6) = .540, p = .167, 95% CI [-.290, .906]. The association between perceived choice and improvement on Block 2 of the delayed transfer test can be viewed in Figure 10.

Figure 10

Association Between Perceived Choice and Improvement on Block 2 of Delayed Transfer Test



Note. In this scatterplot, blue dots represent participants from the experimental group (EG, n = 8), and orange dots represent participants from the control group (CG, n = 8). The line of best fit is shown for the total sample (black), the EG (blue), and the CG (orange). Scores for change from pre-test to Block 2 of the delayed transfer test were obtained by subtracting scores on the modified Box and Block Test at pre-test from Block 2 of the delayed transfer test. Scores for perceived choice were obtained from the "perceived choice" subscale of the Intrinsic Motivation Inventory. In the EG, greater perceived choice had a strong significant association with greater improvement on the delayed transfer test at Block 2, while in the CG, there was no significant association.

4.5 Correlations Between Pre-Test Scores and IMI Subscales

Correlations between pre-test scores (Scooping Task, mBBT, and SAM) and Intrinsic Motivation Inventory subscales were also run in order to explore potentials relationships between baseline motor ability/mood and perception of the task after two days. Both the Scooping Task and the mBBT pre-tests had moderate correlations with the "perceived competence" and the "pressure/tension" subscales of the IMI. The "perceived competence subscale" was positively correlated with scores on both the Scooping Task pre-test, r_s (14) = .506, p = .046, 95% CI [-.002, .806], and the mBBT pre-test, r_s (14) = .596, p = .015, 95% CI [.127, .848], indicating that those with higher pretest scores also had higher perceived competence on the Scooping Task after practicing it for two days. The "pressure/tension" subscale was negatively correlated with scores on the Scooping Task pretest, r_s (14) = -.516, p = .041, 95% CI [-.811, -.012], and the mBBT pre-test, r_s (14) = -.607, p = .013, 95% CI [-.852, -.144], indicating that those with higher pre-test scores had lower perceptions of pressure/tension after the practice phase of the study.

The SAM pre-test was significantly correlated with three of the IMI subscales that were rated on Day 2 following practice. There was a moderate correlation between baseline positive affect and the "interest/enjoyment" subscale, r_s (14) = -.584, p = .017, 95% CI [-.842, -.109]. There was also a strong correlation between positive affect and the "value/usefulness" subscale, r_s (14) = -.679, p = .004, 95% CI [-.882, -.261], as well as a moderate correlation between positive affect and the "effort/importance" subscale, r_s (14) = -.583, p = .018, 95% CI [-.842, -.107]. Thus, participants with more positive affect at baseline also tended to have higher scores on the "interest/enjoyment," "value/usefulness," and "effort/importance" subscales of the IMI that were assessed at Day 2 following practice.

Chapter 5: Discussion

The purpose of this study was to investigate the effects of SCP on motor learning and psychological outcomes for individuals with chronic post-stroke UL impairment. After practicing the Scooping Task for two consecutive days, both groups demonstrated significant 24-hour retention of the trained task. Additionally, both groups improved significantly on an untrained motor task immediately following practice and at the 24-hour follow-up. However, there were no significant differences between groups on any of the motor learning outcomes. There were also no significant differences between groups on any of the psychological outcomes. Still, a moderate-to-strong significant association between perceived choice and improvement on the untrained motor task at follow-up suggests a potential link between perception of autonomy and motor learning for individuals with UL hemiparesis after stroke, even though SCP did not appear to provide a clear benefit on any of the outcomes.

5.1 Motor Learning Outcomes

Primary Outcome (Scooping Task)

In this study, both groups demonstrated significant 24-hour retention of the Scooping Task with their more affected hand following two consecutive days of practice (50 trials each day, 100 trials total). Schaefer et al. (2013) previously demonstrated significant improvement on this task following five consecutive days of practice (50 trials each day, 250 trials total) for individuals with chronic post-stroke hemiparesis. This present study found that performance of the Scooping Task improved significantly after only two days of practice. However, contrary to Hypothesis 1, there was no significant difference between groups on 24-hour retention of the trained motor task. There was a small to medium effect that favored the CG on change from the pre-test to Block 1 ($r = -.247$), and a small to medium effect favored the EG on change from the

pre-test to Block 2 (r = .247) of the 24-hour retention test on Day 3. Generalization of this finding is limited due to the small sample size, and larger samples are needed. However, overall, it does not appear that SCP provided any notable benefit to the EG in 24-hour retention of the task.

This finding is inconsistent with previous research on SCP in other populations that has demonstrated control over practice conditions can lead to improvements in motor retention. In this study, participants in the EG had control over their practice schedule and chose the order in which they practiced blocks of trials with each of their hands. Previous research with healthy individuals has found that control over practice schedule improves motor retention (Keetch & Lee, 2007; Wulf & Adams, 2014). Control over other practice variables such as control over practice difficulty (Leiker et al., 2016) and amount of practice (Lessa & Chiviacowsky, 2015) have also led to improvements in retention. SCP has also been shown to improve retention for a neurological population. Chiviacowsky et al. (2012b) found that control over when to use an assistive device led to improved retention of a balance task for individuals with Parkinson's disease. Thus, it is unclear why SCP did not have the anticipated effect of improved motor retention for this sample of individuals with post-stroke UL hemiparesis.

It is possible that baseline imbalances between groups may have impacted retention of the trained task. There was a significant baseline difference between groups on elbow flexor spasticity that favored the CG; although, there was no significant correlation found between elbow flexor spasticity and change on the retention test. However, other confounding factors such as stroke location may have influenced the outcome. There was a small to medium effect that favored the EG at Block 2 of the retention test, but the CG was favored in Block 1. The EG had a non-significant trend towards improvement between Blocks 1 and 2 of the retention test (z

= 1.56, p = .120), while the CG did not (z = -.07, p = .943); that is, six participants in the EG increased the number of scoops completed between Blocks 1 and 2, while only 3 participants in the CG increased the number of scoops. This can be compared to findings by Wulf et al. (2018) who investigated the effects of making incidental choices on 24-hour retention of a motor task; investigators found that the choice group improved significantly between Blocks 1 and 2 of the retention test, while the control group did not change. Thus, in this study, the EG exhibited similar behavior to healthy subjects who made choices during motor practice; however, SCP does not appear to have provided an overall benefit. Again, due to the small sample size, further investigation is warranted.

Secondary Outcome (mBBT)

Both groups also demonstrated significant improvement on the modified Box and Block Test (mBBT), which was an untrained transfer task, immediately following practice on Day 2 and at the follow-up on Day 3. Schaefer et al. (2013) previously found that practicing the Scooping Task for 5 consecutive days led to significant improvement on the mBBT for individuals with chronic post-stroke hemiparesis. In this present study, both groups demonstrated significant improvement on the mBBT after practicing the Scooping Task for only 2 days.

Immediate Transfer Test. The immediate transfer test was administered 10 minutes after completion of the practice phase on Day 2. The CG demonstrated significant improvement on both Blocks 1 and 2 of the mBBT from the pre-test, while the EG only improved from the pre-test to Block 2 but not Block 1. However, the EG did improve significantly between Blocks 1 and 2, while the CG did not. At Block 2, all eight participants in the CG improved from the pre-test, while only 6 participants in the EG improved from their pre-test score.

There were no significant differences between groups on change from the pre-test to Blocks 1 or 2 of the immediate transfer test, and, therefore, no evidence was found to support Hypothesis 2. There was a moderate effect size that favored the CG on change from the pre-test to Block 1, and the EG demonstrated a small-to-moderate effect over the CG from pre-test to Block 2. There was a significant difference between groups on change between Blocks 1 and 2 of the immediate transfer test that favored the EG. However, it is unclear if this difference is meaningful given that the EG did not demonstrate significantly greater improvement on the task overall, and more participants in the CG improved from their pre-test scores at Block 2 when compared to the EG.

Delayed Transfer Test. The mBBT was also administered at the Day 3 follow-up assessment to measure delayed transfer of learning. Both groups demonstrated significant improvements from the pre-test to Block 1 and Block 2. All eight participants in the CG improved their scores on the mBBT from the pre-test to Blocks 1 and 2, while only six participants in the EG improved from the pre-test to Block 1, and seven improved from the pre-test to Block 2. Support for Hypothesis 2 was not found as there were no significant differences between groups from pre-test to Block 1 or Block 2. The effect size between groups from the pre-test to Block 1 was negligible. There was a small-to-moderate effect size favoring the EG on improvement from the pre-test to Block 2. However, more participants in the CG improved on Blocks 1 and 2 of the delayed transfer test than the EG. Thus, it is unclear from this analysis if SCP provided any benefit for transfer of learning to an untrained task.

This finding differs from previous research on SCP with healthy subjects. Wu and Magill (2011) found that control over practice schedule led to improved immediate and delayed transfer of learning. Control over amount of practice has also been shown to improve transfer of learning

(Lessa & Chiviacowsky, 2015; Post et al., 2011). There was a small to moderate effect size that favored the EG in Block 2 of both the immediate transfer and delayed transfers tests. However, more participants in the CG improved on the transfer tests than the EG. It is possible that SCP may have benefitted some participants in the EG on transfer of learning but not all. Further investigation with larger samples is needed.

5.2 Psychological Outcomes

Based on evidence from research with healthy individuals and theoretical assumptions, it was hypothesized that SCP would lead to increased positive affect, self-efficacy, and intrinsic motivation. However, no statistically significant differences were found between groups on any of these outcomes.

Positive Affect

Overall, both groups had positive ratings of mood throughout the study. At baseline, the CG had slightly more positive affect than the EG, but this difference was not significant. Ratings of mood on Day 2 and 3 were similar between groups with no significant differences. There was a non-significant trend in the EG towards increased positive affect after the completion of the practice phase on Day 2 that was not seen in the CG. Although the difference between groups on change in mood from Day 1 pre-test to Day 2 post-test was not significant, there was a moderate effect size that favored the EG over the CG.

Ratings of mood were not associated with change on any of the motor learning outcomes. This finding contrasts with research by Wulf et al. (2018) who investigated the effects of incidental choice on motor learning. The investigators hypothesized that positive affect could indicate activation of the dopaminergic system and used the Self-Assessment Manikin scale to measure positive affect. They found that the choice group had more positive affect than the

control group after the practice phase and also found that the rating of affect following the practice phase predicted performance on the retention test. When exploring the effects of autonomy-supportive language on motor learning, Hooyman et al. (2014) also found that the group that received autonomy-supportive instructions had increased positive affect when compared to the control group, who received controlling instructions. Previous research has also suggested that positive affect may mediate the relationship between autonomous motivation and performance (Gillet et al., 2013).

While this current study did not find any significant differences between groups, it is limited by a small sample size. As the EG did demonstrate a trend towards increased positive affect after the practice phase, it is possible that SCP had a positive effect on mood. However, change in affect did not correlate with change on any of the motor learning outcomes, and there was no significant correlation between positive affect and improvement on motor learning outcomes in this study.

Self-Efficacy

Contrary to Hypothesis 3, no differences between groups were found on self-efficacy ratings for performance of the Scooping Task. On Day 2, there was a small-to-medium effect that favored the CG on the self-efficacy rating for the maximum score. However, this trend was not seen in self-efficacy ratings for the median or max-plus scores, where small effect sizes favored the EG. On Day 3, both groups had the same median scores for each of the three self-efficacy ratings. None of the self-efficacy ratings were significantly correlated with change on the motor learning outcomes.

Self-efficacy has previously been linked with autonomy-support in motor learning research. Hooyman et al. (2014) also found that those who received autonomy-supportive

instructions had increased self-efficacy compared to those who received controlling instructions for a novel throwing task. Additionally, previous motor learning research with healthy subjects found that self-efficacy following motor practice predicted transfer of learning (Chiviacowsky et al., 2012a). For individuals with post-stroke UL hemiparesis, self-efficacy of arm use has been shown to correlate with both sensorimotor capacity and actual use of the UL (Buxbaum et al., 2020). Stewart et al. (2019) also found that self-efficacy for reaching accuracy was correlated with endpoint error during reaching performance for individuals with chronic stroke. In this current study, self-efficacy was not significantly correlated with change on motor learning outcomes and also did not differ between groups. Thus, the connections between self-efficacy, SCP, and motor learning remain unclear for those with UL impairment due to stroke.

Intrinsic Motivation Inventory

No significant differences were found between groups on the subscales of the Intrinsic Motivation Inventory (IMI), contrary to Hypothesis 3. Analysis of effect sizes found that the EG was favored on the "interest/enjoyment" and "perceived choice" subscales with small and medium effect sizes, respectively. The CG was favored on the "perceived competence" and "value/usefulness" subscales with medium effect sizes and the "effort/importance" subscale with a large effect size.

Interest/Enjoyment. The "interest/enjoyment" subscale of the IMI is considered the measure of intrinsic motivation. In this study, baseline positive affect was moderately correlated with interest/enjoyment following the practice phase, so those with more positive mood at baseline may have enjoyed the task more. While there were no significant differences between groups, there was a small effect size that favored the EG. This finding can be compared with results of a study on SCP with individuals with Parkinson's disease. Chiviacowsky et al. (2012b)

found that the SCP group reported significantly higher overall motivation to learn the task than the control group, but there was no difference between groups on how much they enjoyed practicing the task. In contrast, Leiker et al. (2016) did find a significant difference between groups on the interest/enjoyment subscale of the IMI that favored the SCP group in a study with healthy subjects that investigated control over difficulty level on a video game. However, similar to this present study, there was no significant relationship between interest/enjoyment and motor learning. Thus, the connection between intrinsic motivation and motor learning remains unclear.

Perceived Competence. While there was no significant difference between groups on perception of competence, a medium effect size favored the CG. Previous research has connected perceptions of competence in healthy subjects with amount of success during task practice; those who perceive less success during practice may have reduced perceptions of competence as well as reduced motor learning (Chiviacowsky et al., 2012a). This study included participants with a wide variety of levels of arm function, and there was a moderate correlation between motor learning pre-test scores and perceived competence that was assessed on Day 2 after the practice phase. Thus, those with greater UL impairment may have found the task more difficult, which may be linked with lower perceived competence following practice. However, based on the limited sample in this study, it does not appear that SCP had a positive effect on perceived competence.

Perceived Choice. Previous research with healthy subjects has shown that autonomy-supportive motor learning interventions can increase perception of choice (Hooyman et al., 2014). Perception of control may have a larger impact on behavior and motivation than actual control in a situation (Ly et al., 2019). Because participants in the EG made choices regarding their practice schedule while CG participants did not make choices, it was hypothesized that the

EG would also have higher perception of choice. While there was no significant difference between groups on the "perceived choice" subscale of the IMI, there was a moderate effect size between groups that favored the EG. Given the small sample, it is possible that some participants in the EG experienced increased perception of choice as a result of having control over the practice schedule.

Interestingly, the "perceived choice" subscale was the only psychological outcome that was significantly correlated with change on a motor learning outcome. Those who had higher perceived choice also had greater change on performance of the untrained motor task on Day 3. In subgroup analysis, there was a strong significant correlation between perceived choice and change on Block 2 of the delayed transfer test in the EG, but there was no significant correlation in the CG. This suggests that the link between the two variables may have been stronger for participants who were actively making choices during practice. Even though all participants in the EG made choices during practice, some indicated both lower perception of choice and also had less transfer of learning to the untrained task. It is possible that some participants in the EG may not have perceived decision-making during practice as being helpful. In other words, making choices during practice may not have increased their *perception* of autonomy and control, which may have been related to reduced improvement on the untrained task. Some participants may have experienced "choice overload," which could have occurred due to fear of making the wrong choice or not having enough expertise to choose correctly (Reutskaja et al., 2018). Research has suggested that SCP may increase information processing, leading to improved motor learning due to active engagement in the task (Leiker et al., 2016; Pathania et al., 2019). However, following stroke, impaired information processing is common (Mahon et

al., 2020), and, for some, making choices during practice could potentially increase the demands of the task beyond an optimal level.

Pressure/Tension. Intrinsic motivation is thought to be inversely related to perceived pressure and tension during task performance; the more someone enjoys a given task, the less they pressure or tension they would be expected to have. In this study, it was hypothesized that SCP would lead to decreased pressure and tension. Chiviacowsky and colleagues (2012b) found that individuals with Parkinson's disease felt less nervous when practicing a balance task when they were given control over when to use a balance pole when compared to those who were not given a choice. Contrastingly, in this current study, there was no significant difference between groups, and the effect size between groups was negligible. However, the "pressure/tension" subscale was negatively correlated with baseline performance on the motor outcomes, which suggests that those with greater UL impairment may have experienced greater pressure and tension during task practice.

Value/Usefulness and Effort/Importance. The "value/usefulness" and "effort/importance" subscales of the IMI are not considered measures of intrinsic motivation. Rather, they are thought to relate to autonomous motivation, in which engagement in an activity is connected with one's personal values and sense of self and is not necessarily related to interest and enjoyment (Deci et al., 1994; Sanli et al., 2013; Self-Determination Theory, n.d.). While there were no significant differences between groups on these subscales, a moderate effect size on the "value/usefulness" subscale and a large effect size on the "effort/importance" subscale both favored the CG. It is possible that some participants in the CG may have valued the expertise of the therapist and appreciated receiving specific instructions regarding their practice schedule, while some in the EG may have doubted their ability to choose appropriately. It should

also be noted that baseline positive affect was strongly correlated with the "value/usefulness" subscale and moderately correlated with the "effort/importance" subscale. Participants with more positive mood at baseline may have been predisposed to value the task more highly and to exert more effort during practice. However, more research is needed to investigate these possibilities.

5.3 Clinical Implications

This study demonstrated that repetitive practice of a simulated feeding task for two consecutive days led to significant improvement on the trained task as well as an untrained transfer task for individuals with chronic post-stroke UL impairment. However, it is unclear if control over their practice schedule provided participants with additional benefit, as the overall results on the motor learning outcomes are mixed. Although there was a small to moderate effect size that favored the EG at Block 2 of the delayed transfer test, not all EG participants improved, while all of the CG participants did demonstrate improvements on the untrained task. Additionally, results from the psychological outcomes appear mixed and do not clearly favor one group over the other. However, a significant association between perception of choice and improvement on the untrained task at Day 3 suggests that autonomy may be an active ingredient for motor learning after stroke. It is possible that, following stroke, some individuals may benefit from SCP while others may not.

SCP has previously been incorporated into complex rehabilitation interventions for UL recovery post-stroke (Lewthwaite et al., 2018; Winstein, et al., 2016b) due to evidence supporting its efficacy in improving motor learning for a variety of populations (Sanli et al., 2013; Wulf & Lewthwaite, 2016). However, for individuals with chronic stroke, intervention responses may be impacted by multiple factors, including lesion location, previous experiences with rehabilitation, and individual psychological factors. Occupational and physical therapists

must be able to structure UL practice in a way that optimizes motivation and engagement in order to maximize functional improvement and recovery. While it has largely been assumed that providing opportunities for choice during practice will lead to greater gains, it may not be so simple for individuals who have experienced a stroke. Therapists should consider individual responses to different components of complex interventions and structure practice in a way that suits individual needs and preferences. Measurement of psychological factors such as perceived choice can help therapists adapt interventions to match the specific needs of the individual.

5.4 Limitations

This study had several limitations, which include the sample size, the inclusion criteria, the overall study design, the trained task, and the outcome measures.

Sample Size. This study was limited by its small sample size, which poses challenges to generalizability and increases the likelihood of type II error, in which there is not enough statistical power to detect differences between groups.

Inclusion Criteria. Two participants who met inclusion criteria for the study were not able to complete study procedures due to an inappropriate degree of fatigue and inability to perform the trained task, indicating that the inclusion criteria for UL function was too broad. This was particularly problematic because participants were paired in this study. When a participant in the EG was unable to complete the procedures, the CG participant they were paired with had to be repaired and rerandomized in order to complete the study. In this study, only one participant was rerandomized, and this individual was also ultimately unable to complete the study. However, this points to issues with using a yoked control group in research with a clinical population, particularly with a randomized design.

Study Design. In this study, participants were first paired and then were randomized into either EG or CG. This was done because the CG participant was dependent on the choices made by the EG participant; in other words, the CG participant had to wait to complete the study until the EG participant first completed it. Participants, however, had scheduling conflicts or limited time frames with which they could complete the study procedures. For examples, some participants received regular botulinum toxin injections every three to four months. Study inclusion criteria required that participants wait at least three months from their last injection before beginning the study, so some participants only had brief time frame when they were willing to complete the study before receiving their next injection. Stratification offered another challenge because participants could not be paired and randomized until two were accrued in a stratum. Thus, some participants had to wait once accrued because there was not yet another participant in their stratum with whom they could be paired.

Most research on SCP has been conducted with healthy individuals, where the challenges with this type of study design may be easier to navigate. The challenges faced in this current study with implementing this type of research design have not been discussed in the literature to the best of my knowledge. Chiviacowsky and colleagues (2012b) used a quasi-randomized study design to investigate the effects of SCP on motor learning with a clinical population (Parkinson's disease). In their study, participants were assigned to groups based on gender and clinical stage; however, there was no discussion of how participants were paired or if any methods were used to prevent bias in group allocation. Their method may have been more feasible than the randomization procedure that was used in this current study; however, this current study prioritized randomization in order to prevent bias with group allocation, even though the randomization procedures introduced pragmatic challenges.

Another limitation of this study was that, although participants were stratified by level of arm function, they were not stratified according to location of their stroke. Some research has noted differences motor skill performance (Bernspång & Fisher, 1995) and neural activity (Fernandes et al., 2021; Liew et al., 2018) depending on stroke location, which may have impacted the results of this study. A crossover design, in which each subject receives both choice and non-choice conditions, may help control for differences in stroke location. However, this type of design would also introduce new issues. To investigate changes in motor learning, an adequate amount of practice is needed for retention and transfer, and a washout period would be needed before testing the second condition. Also, in a crossover trial, the order that the two conditions are implemented should be randomized to minimize learning and order effects. However, in research designs that investigate SCP, the control condition depends on choices that are made in the experimental condition, so the experimental condition must be completed first. If the control condition was implemented second for all subjects, then an order effect could be introduced with no way to control for it.

Choice is challenging to study in an experimental design because the variable that participants have control over cannot be held constant between groups. The yoked control group has been implemented as a way to control for this. However, this type of design requires that subjects are not independent. The matched pairing should then be accounted for in the analysis, and the order in which subjects complete the study is determined by the condition they are allocated to. Choice has also been investigated in a within-subjects design where immediate responses to both choice and non-choice conditions are measured (Murayama et al., 2015). However, this type of design would not be able to determine differences in learning between the two conditions, only immediate responses and performance. Thus, further consideration is

needed to develop research designs that can investigate the effects of choice on motor learning outcomes for clinical populations.

Trained Task. Another limitation of the study is that the trained task did not prevent participants from compensating with their trunk and did not allow for adjustment of difficulty level based on level of function. Improvements seen in this study could have resulted from increased use of compensatory movement strategies rather than improvements in movement quality. Additionally, all participants practiced the same task regardless of their level of arm function; the difficulty of the task was not adjusted to account for baseline arm function. It is well known that an appropriate level of difficulty is necessary for optimal motor learning to occur (Maier et al., 2019). The task may not have provided an optimal level of challenge to all participants and could have been too difficult for some. Those who had lower baseline scores on the Scooping Task also tended to have lower perceptions of competence and higher perceptions of pressure/tension after two days of practice. Thus, variations in task difficulty among subjects may have introduced a confounding variable into the study that could have influenced outcomes.

Outcome Measures. Another limitation of this study was that the outcome measures were not shown to be reliable and valid with the stroke population. For the motor learning outcomes, although formal reliability and validity testing was not conducted, previous research has shown that both the Scooping Task and the mBBT were responsive to change (Schaefer et al., 2013). The mBBT is also a modified version of the BBT, which is a valid and reliable assessment of dexterity for the stroke population (Chen et al., 2009; Lin et al., 2010).

The psychological outcomes also have not been validated or shown to be reliable with the stroke population. First, while the IMI is the most commonly used assessment of motivation for stroke rehabilitation interventions, formal psychometric testing should be conducted with this

population. Additionally, this study used an adapted 28-item scale that was constructed based on the recommendations of IMI authors, and so further testing of the reliability and validity of this specific scale with the stroke population is warranted.

Second, although the self-efficacy scale used in this study was constructed using Bandura's guidelines, the scores that were rated were adapted to meet the specific needs of this study. It is unclear if having participants rate their confidence in obtaining median, maximum, and "max-plus" scores from practice is a valid way to measure self-efficacy. However, in this study both groups demonstrated similar trends when rating these scores, with greater confidence in obtaining their median score and progressively lower confidence in obtaining maximum and max-plus scores. Psychometric testing with larger samples should be conducting to determine if this is a valid and reliable method for measuring self-efficacy with the stroke population.

Third, the valance subscale of the SAM was selected to measure positive affect in this study because Wulf and colleagues (2018) had previously shown that choice during motor practice led to increase positive affect, which then predicted improvements in motor learning with a healthy population. However, in this study, participants' emotional state may have been influenced by factors other than the research. Because practice took place over two days, events unrelated to the study could have impacted participants' moods from the pre-test to the post-test. Further psychometric testing is needed to determine if this type of assessment is valid and reliable within this context.

5.5 Directions for Future Research

Future research should further investigate the impact of SCP and perceived autonomy on motor learning for individuals with post-stroke UL impairment. This may require the development of several smaller research questions that can address different components of this

complex issue. It may be beneficial to consider study designs that allow subjects to serve as their own control to limit the impact of individual factors such as lesion location. Because the location of the stroke may impact motor learning ability and outcomes (Edwardson et al., 2017; Fernandes et al., 2021), further work is needed to investigate this, especially during SCP. This can be explored by investigating differences in neural activation patterns during autonomous vs. controlled conditions within the context of motor practice for both stroke survivors and healthy controls, measured by electroencephalography (EEG) and/or functional magnetic resonance imaging (fMRI).

Future research should also consider factors related to the trained motor task. The Scooping Task, which was used in this dissertation, did not prevent participants from compensating with their trunk, so improvements may have occurred from increased use of compensatory movement patterns rather than recovery of motor ability. Using a task apparatus that prevents use of common movement compensations and measures kinematic outcomes can help measure improvements in movement quality, rather than only task completion. Additionally, the Scooping Task did not have an adjustable level of difficulty, so the task was much easier for some participants than others, potentially influencing outcomes. Ideally, the trained motor task should have an adjustable level of difficulty to accommodate different levels of UL impairment so that task difficulty level can be controlled. Technologies such as virtual reality or robotic systems that can adjust the level of task difficulty and measure kinematic outcomes should be considered in future research designs to help limit confounding variables and better determine improvements in motor capacity.

Further studies are also needed to explore the relationship between psychological variables and motor learning after stroke. More research is needed to determine reliability and

validity of motivational outcome measures for stroke rehabilitation. Additionally, while some work has been done to determine factors that predict motor recovery and arm use after stroke (Barker et al., 2007; Buxbaum et al., 2020), future research should examine the relationship between psychological variables and motor learning outcomes, particularly with regard to perceived choice and transfer of learning. Another important consideration is differentiating trait psychological variables (relatively stable characteristics that differ between individuals) from state psychological variables (changes that occur within an individual based on the situation; Zilcha-Mano & Webb, 2021). In research, trait characteristics can be used as predictors or moderators, while state psychological variables can be measured over time can help determine mechanisms of change in interventions (Zilcha-Mano & Webb, 2021). Because those with divergent trait characteristics may respond differently to a given intervention, measuring both trait and state psychological variables can potentially help explain how psychological factors relate to motor learning interventions for stroke survivors. This study only measured variables related to the individual's current psychological state. Future research should also measure trait psychological variables to determine if different baseline characteristics predict or moderate outcomes.

Future research should also consider whether differences in context and setting have an effect on one's confidence when making choices related to practice. Choices may be perceived differently in medical settings or during therapeutic interventions than in other real-world contexts, potentially impacting outcomes. Within the context of rehabilitation interventions, therapists may be viewed by their patients as experts, and some stroke survivors may not feel comfortable making choices about how to practice, which could potentially limit the impact of choice-based interventions. Investigating beliefs related to making choices during rehabilitation

interventions may help expand our current understanding of the construct of autonomy and guide the development of future interventions. Finally, time-efficient evaluation methods should be developed that allow therapist to quickly assess whether patients are responsive to specific practice conditions, such as SCP. This may help therapists create interventions that are responsive to individual needs using structured methodology that optimizes motivation and engagement.

5.6 Conclusions

The findings of this study provide preliminary data on the effects of SCP on motor learning for those with UL hemiparesis after stroke as well as data on self-efficacy, intrinsic motivation, and positive affect. SCP has been incorporated into complex motor learning interventions for stroke rehabilitation because it is believed to be important active ingredient for skill acquisition. Based on the results of this study, the effects of SCP on motor learning for stroke survivors with UL hemiparesis remain unclear. However, there does appear to be a relationship between perceived choice during motor practice and transfer of learning to an untrained task. Perceptions of autonomy and control may be more important than actual choice during motor practice, and while some stroke survivors may benefit from SCP, others may not. More research is needed to investigate how stroke survivors respond to SCP and choice during motor practice. Additionally, the relationships between psychological variables and motor learning outcomes should be further examined. This can help determine mechanisms of action in complex stroke rehabilitation interventions in order to improve intervention effectiveness and functional outcomes.

References

Alawieh, A., Zhao, J., & Feng, W. (2018). Factors affecting post-stroke motor recovery: Implications on neurotherapy after brain injury. *Behavioural Brain Research*, *340*, 94–101. https://doi.org/10.1016/j.bbr.2016.08.029

Ballester, B. R., Ward, N. S., Brander, F., Maier, M., Kelly, K., & Verschure, P. F. M. J. (2022a). Relationship between intensity and recovery in post-stroke rehabilitation: a retrospective analysis. *Journal of Neurology, Neurosurgery, and Psychiatry*, *93*(2), 226–228. https://doi.org/10.1136/jnnp-2021-326948

Ballester, B. R., Winstein, C., & Schweighofer, N. (2022b). Virtuous and vicious cycles of arm use and function post-stroke. *Frontiers in Neurology*, *13*, 804211. https://doi.org/10.3389/fneur.2022.804211

Bandura, A. (2006). Guide for Constructing Self-Efficacy Scales. In F. Pajares & T. Urdan (Eds.), *Self-Efficacy Beliefs of Adolescents* (pp. 307–337). Information Age Publishing.

Barker, R. N., Gill, T. J., & Brauer, S. G. (2007). Factors contributing to upper limb recovery after stroke: a survey of stroke survivors in Queensland Australia. *Disability and Rehabilitation*, *29*(13), 981–989. https://doi.org/10.1080/09638280500243570

Bernspång, B., & Fisher, A. G. (1995). Differences between persons with right or left cerebral vascular accident on the Assessment of Motor and Process Skills. *Archives of Physical Medicine and Rehabilitation*, *76*(12), 1144–1151. https://doi.org/10.1016/s0003-9993(95)80124-3

Bernstein, N. A. (1967). *The co-ordination and regulation of movements*. Pergamon Press.

Bohannon, R. W., & Smith, M. B. (1987). Interrater reliability of a modified Ashworth scale of muscle spasticity. *Physical Therapy*, *67*(2), 206–207. https://doi.org/10.1093/ptj/67.2.206

Boyd, L., & Winstein, C. (2006). Explicit information interferes with implicit motor learning of both continuous and discrete movement tasks after stroke. *Journal of Neurologic Physical Therapy*, *30*(2), 46–59. https://doi.org/10.1097/01.npt.0000282566.48050.9b

Bradley, C. L., & Damiano, D. L. (2019). Effects of dopamine on motor recovery and training in adults and children with nonprogressive neurological injuries: a systematic review. *Neurorehabilitation and Neural Repair*, *33*(5), 331–344. https://doi.org/10.1177/1545968319837289

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: the Self-Assessment Manikin and the Semantic Differential. *Journal of Behavior Therapy and Experimental Psychiatry*, *25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9

Buxbaum, L. J., Varghese, R., Stoll, H., & Winstein, C. J. (2020). Predictors of arm nonuse in chronic stroke: a preliminary investigation. *Neurorehabilitation and Neural Repair*, *34*(6), 512–522. https://doi.org/10.1177/1545968320913554

Chen, H. M., Chen, C. C., Hsueh, I. P., Huang, S. L., & Hsieh, C. L. (2009). Test-retest reproducibility and smallest real difference of 5 hand function tests in patients with stroke. *Neurorehabilitation and Neural Repair*, *23*(5), 435–440. https://doi.org/10.1177/1545968308331146

Chiang, K. S., Green, K. E., & Cox, E. O. (2009). Rasch analysis of the Geriatric Depression Scale-Short Form. *The Gerontologist*, *49*(2), 262–275. https://doi.org/10.1093/geront/gnp018

Chiviacowsky, S., Wulf, G., & Lewthwaite, R. (2012a). Self-controlled learning: the importance of protecting perceptions of competence. *Frontiers in Psychology*, *3*, 458. https://doi.org/10.3389/fpsyg.2012.00458

Chiviacowsky, S., Wulf, G., Lewthwaite, R., & Campos, T. (2012b). Motor learning benefits of self-controlled practice in persons with Parkinson's disease. *Gait & Posture*, *35*(4), 601–605. https://doi.org/10.1016/j.gaitpost.2011.12.003

Cirstea, M. C., Ptito, A., & Levin, M. F. (2003). Arm reaching improvements with short-term practice depend on the severity of the motor deficit in stroke. *Experimental Brain Research*, *152*(4), 476–488. https://doi.org/10.1007/s00221-003-1568-4

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037//0033-2909.112.1.155

Cools, R., Froböse, M., Aarts, E., & Hofmans, L. (2019). Dopamine and the motivation of cognitive control. *Handbook of Clinical Neurology*, *163*, 123–143. https://doi.org/10.1016/B978-0-12-804281-6.00007-0

Cramer, S. C., Sur, M., Dobkin, B. H., O'Brien, C., Sanger, T. D., Trojanowski, J. Q., Rumsey, J. M., Hicks, R., Cameron, J., Chen, D., Chen, W. G., Cohen, L. G., deCharms, C., Duffy, C. J., Eden, G. F., Fetz, E. E., Filart, R., Freund, M., Grant, S. J., … Vinogradov, S. (2011). Harnessing neuroplasticity for clinical applications. *Brain: A Journal of Neurology*, *134*(6), 1591–1609. https://doi.org/10.1093/brain/awr039

Deci, E. L., Eghrari, H., Patrick, B. C., & Leone, D. R. (1994). Facilitating internalization: the self-determination theory perspective. *Journal of Personality*, *62*(1), 119–142. https://doi.org/10.1111/j.1467-6494.1994.tb00797.x

Deci, E. L., & Ryan, R. M. (2008). Facilitating optimal motivation and psychological well-being across life's domains. *Canadian Psychology*, *49*(1), 14–23. https://doi.org/10.1037/0708-5591.49.1.14

Dewald, J. P., Pope, P. S., Given, J. D., Buchanan, T. S., & Rymer, W. Z. (1995). Abnormal muscle coactivation patterns during isometric torque generation at the elbow and shoulder in hemiparetic subjects. *Brain: A Journal of Neurology*, *118*(2), 495–510. https://doi.org/10.1093/brain/118.2.495

Di Domenico, S. I., & Ryan, R. M. (2017). The emerging neuroscience of intrinsic motivation: a new frontier in self-determination research. *Frontiers in Human Neuroscience*, *11*, 1–14. https://doi.org/10.3389/fnhum.2017.00145

Dzewaltowski, A. C., Hedrick, E. A., Leutzinger, T. J., Remski, L. E., & Rosen, A. B. (2021). The effect of split-belt treadmill interventions on step length asymmetry in individuals poststroke: a systematic review with meta-analysis. *Neurorehabilitation and Neural Repair*, *35*(7), 563–575. https://doi.org/10.1177/15459683211011226

Edwardson, M. A., Wang, X., Liu, B., Ding, L., Lane, C. J., Park, C., Nelsen, M. A., Jones, T. A., Wolf, S. L., Winstein, C. J., & Dromerick, A. W. (2017). Stroke lesions in a large upper limb rehabilitation trial cohort rarely match lesions in common preclinical models. *Neurorehabilitation and Neural Repair*, *31*(6), 509–520. https://doi.org/10.1177/1545968316688799

Espie, C. A., Kyle, S. D., Hames, P., Gardani, M., Fleming, L., & Cape, J. (2014). The Sleep Condition Indicator: a clinical screening tool to evaluate insomnia disorder. *BMJ Open*, *4*(3), e004183. https://doi.org/10.1136/bmjopen-2013-004183

Feigin, V. L., Stark, B. A., Johnson, C. O., Roth, G. A., Bisignano, C., Abady, G. G., Abbasifard, M., Abbasi-Kangevari, M., Abd-Allah, F., Abedi, V., Abualhasan, A., Abu-Rmeileh, N. M., Abushouk, A. I., Adebayo, O. M., Agarwal, G., Agasthi, P., Ahinkorah, B. O., Ahmad, S., Ahmadi, S., … Murray, C. J. L. (2021). Global, regional, and national burden of stroke and

its risk factors, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet Neurology*, *20*(10), 795–820. https://doi.org/10.1016/S1474-4422(21)00252-0

Fernandes, A. B. G. S., de Melo, J. C. P., de Oliveira, D. C., Cavalcanti, F. A. D. C., Postolache, O. A., Passos, P. J. M., & Campos, T. F. (2021). Is motor learning of stroke patients in non-immersive virtual environment influenced by laterality of injury? A preliminary study. *Journal of Bodywork and Movement Therapies*, *25*, 53–60. https://doi.org/10.1016/j.jbmt.2020.10.015

Fleming, M. K., Smejka, T., Henderson Slater, D., Chiu, E. G., Demeyere, N., & Johansen-Berg, H. (2021). Self-reported and objective sleep measures in stroke survivors with incomplete motor recovery at the chronic stage. *Neurorehabilitation and Neural Repair*, *35*(10), 851–860. https://doi.org/10.1177/15459683211029889

Fu, V., Weatherall, M., McPherson, K., Taylor, W., McRae, A., Thomson, T., Gommans, J., Green, G., Harwood, M., Ranta, A., Hanger, C., Riley, J., & McNaughton, H. (2020). Taking Charge after Stroke: A randomized controlled trial of a person-centered, self-directed rehabilitation intervention. *International Journal of Stroke*, *15*(9), 954–964. https://doi.org/10.1177/1747493020915144

Gauthier, L. V, Taub, E., Perkins, C., Ortmann, M., Mark, V. W., & Uswatte, G. (2008). Remodeling the brain: plastic structural brain changes produced by different motor therapies after stroke. *Stroke*, *39*(5), 1520–1525. https://doi.org/10.1161/STROKEAHA.107.502229

Gillet, N., Vallerand, R. J., Lafrenière, M.-A. K., & Bureau, J. S. (2013). The mediating role of positive and negative affect in the situational motivation-performance relationship. *Motivation and Emotion*, *37*(3), 465–479. https://doi.org/10.1007/s11031-012-9314-5

Goldstein, L. B., Bertels, C., & Davis, J. N. (1989). Interrater reliability of the NIH stroke scale. *Archives of Neurology*, *46*(6), 660–662. https://doi.org/10.1001/archneur.1989.00520420080026

Gower, A., & Tiberi, M. (2018). The intersection of central dopamine system and stroke: potential avenues aiming at enhancement of motor recovery. *Frontiers in Synaptic Neuroscience*, *10*, 18. https://doi.org/10.3389/fnsyn.2018.00018

Gregor, S., Saumur, T. M., Crosby, L. D., Powers, J., & Patterson, K. K. (2021). Study paradigms and principles investigated in motor learning research after stroke: a scoping review. *Archives of Rehabilitation Research and Clinical Translation*, *3*(2), 100111. https://doi.org/10.1016/j.arrct.2021.100111

Guidetti, S., Ytterberg, C., Ekstam, L., Johansson, U., & Eriksson, G. (2014). Changes in the impact of stroke between 3 and 12 months post-stroke, assessed with the Stroke Impact Scale. *Journal of Rehabilitation Medicine*, *46*(10), 963–968. https://doi.org/10.2340/16501977-1865

Halperin, I., Chapman, D. W., Martin, D. T., Lewthwaite, R., & Wulf, G. (2017). Choices enhance punching performance of competitive kickboxers. *Psychological Research*, *81*(5), 1051–1058. https://doi.org/10.1007/s00426-016-0790-1

Hayward, K. S., Barker, R. N., Carson, R. G., & Brauer, S. G. (2014). The effect of altering a single component of a rehabilitation programme on the functional recovery of stroke

patients: a systematic review and meta-analysis. *Clinical Rehabilitation*, *28*(2), 107–117. https://doi.org/10.1177/0269215513497601

Hebscher, M., & Gilboa, A. (2016). A boost of confidence: The role of the ventromedial prefrontal cortex in memory, decision-making, and schemas. *Neuropsychologia*, *90*, 46–58. https://doi.org/10.1016/j.neuropsychologia.2016.05.003

Hiser, J., & Koenigs, M. (2018). The multifaceted role of the ventromedial prefrontal cortex in emotion, decision making, social cognition, and psychopathology. *Biological Psychiatry*, *83*(8), 638–647. https://doi.org/10.1016/j.biopsych.2017.10.030

Hooyman, A., Wulf, G., & Lewthwaite, R. (2014). Impacts of autonomy-supportive versus controlling instructional language on motor learning. *Human Movement Science*, *36*, 190–198. https://doi.org/10.1016/j.humov.2014.04.005

Houwink, A., Nijland, R. H., Geurts, A. C., & Kwakkel, G. (2013). Functional recovery of the paretic upper limb after stroke: who regains hand capacity? *Archives of Physical Medicine and Rehabilitation*, *94*(5), 839–844. https://doi.org/10.1016/j.apmr.2012.11.031

Iwatsuki, T., Abdollahipour, R., Psotta, R., Lewthwaite, R., & Wulf, G. (2017). Autonomy facilitates repeated maximum force productions. *Human Movement Science*, *55*, 264–268. https://doi.org/10.1016/j.humov.2017.08.016

Jaquess, K. J., Lu, Y., Ginsberg, A., Kahl, S., Lu, C., Ritland, B., Gentili, R. J., & Hatfield, B. D. (2021). Effect of self-controlled practice on neuro-cortical dynamics during the processing of visual performance feedback. *Journal of Motor Behavior*, *53*(5), 632–643. https://doi.org/10.1080/00222895.2020.1817841

Jaquess, K. J., Lu, Y., Iso-Ahola, S. E., Zhang, J., Gentili, R. J., & Hatfield, B. D. (2020). Self-controlled practice to achieve neuro-cognitive engagement: underlying brain processes to

enhance cognitive-motor learning and performance. *Journal of Motor Behavior*, *52*(5), 544–557. https://doi.org/10.1080/00222895.2019.1651245

Jeon, B. J., Kim, W. H., & Park, E. Y. (2015). Effect of task-oriented training for people with stroke: a meta-analysis focused on repetitive or circuit training. *Topics in Stroke Rehabilitation*, *22*(1), 34–43. https://doi.org/10.1179/1074935714Z.0000000035

Joy, M. T., & Carmichael, S. T. (2021). Encouraging an excitable brain state: mechanisms of brain repair in stroke. *Nature Reviews Neuroscience*, *22*(1), 38–53. https://doi.org/10.1038/s41583-020-00396-7

Kaefer, A., Chiviacowsky, S., Meira, C. de M., & Tani, G. (2014). Self-controlled practice enhances motor learning in introverts and extroverts. *Research Quarterly for Exercise and Sport*, *85*(2), 226–233. https://doi.org/10.1080/02701367.2014.893051

Kal, E. C., Van Der Kamp, J., Houdijk, H., Groet, E., Van Bennekom, C. A. M., & Scherder, E. J. A. (2015). Stay focused! The effects of internal and external focus of attention on movement automaticity in patients with stroke. *PLoS ONE*, *10*(8), 1–18. https://doi.org/10.1371/journal.pone.0136917

Kal, E., Houdijk, H., van der Kamp, J., Verhoef, M., Prosée, R., Groet, E., Winters, M., van Bennekom, C., & Scherder, E. (2019). Are the effects of internal focus instructions different from external focus instructions given during balance training in stroke patients? A double-blind randomized controlled trial. *Clinical Rehabilitation*, *33*(2), 207–221. https://doi.org/10.1177/0269215518795243

Kantak, S. S., Zahedi, N., & McGrath, R. (2017). Complex skill training transfers to improved performance and control of simpler tasks after stroke. *Physical Therapy*, *97*(7), 718–728. https://doi.org/10.1093/ptj/pzx042

Keetch, K. M., & Lee, T. D. (2007). The effect of self-regulated and experimenter-imposed practice schedules on motor learning for tasks of varying difficulty. *Research Quarterly for Exercise and Sport*, *78*(5), 476–486. https://doi.org/10.1080/02701367.2007.10599447

Kim, G. J., Hinojosa, J., Rao, A. K., Batavia, M., & O'Dell, M. W. (2017). Randomized trial on the effects of attentional focus on motor training of the upper extremity using robotics with individuals after chronic stroke. *Archives of Physical Medicine and Rehabilitation*, *98*(10), 1924–1931. https://doi.org/10.1016/j.apmr.2017.06.005

Kleim, J. A., Barbay, S., & Nudo, R. J. (1998). Functional reorganization of the rat motor cortex following motor skill learning. *Journal of Neurophysiology*, *80*(6), 3321–3325. https://doi.org/10.1152/jn.1998.80.6.3321

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. *Journal of Speech, Language, and Hearing Research*, *51*(1), S225-S239. https://doi.org/10.1044/1092-4388(2008/018)

Krakauer, J. W., Hadjiosif, A. M., Xu, J., Wong, A. L., & Haith, A. M. (2019). Motor learning. *Comprehensive Physiology*, *9*(2), 613–663. https://doi.org/10.1002/cphy.c170043

Kuriakose, D., & Xiao, Z. (2020). Pathophysiology and treatment of stroke: present status and future perspectives. *International Journal of Molecular Sciences*, *21*(20), 7609. https://doi.org/10.3390/ijms21207609

Lang, C. E., & Schieber, M. H. (2004). Reduced muscle selectivity during individuated finger movements in humans after damage to the motor cortex or corticospinal tract. *Journal of Neurophysiology*, *91*(4), 1722–1733. https://doi.org/10.1152/jn.00805.2003

Legault, L., & Inzlicht, M. (2013). Self-determination, self-regulation, and the brain: autonomy improves performance by enhancing neuroaffective responsiveness to self-regulation

failure. *Journal of Personality and Social Psychology*, *105*(1), 123–138. https://doi.org/10.1037/a0030426

Leiker, A. M., Bruzi, A. T., Miller, M. W., Nelson, M., Wegman, R., & Lohse, K. R. (2016). The effects of autonomous difficulty selection on engagement, motivation, and learning in a motion-controlled video game task. *Human Movement Science*, *49*, 326–335. https://doi.org/10.1016/j.humov.2016.08.005

Leotti, L. A., Iyengar, S. S., & Ochsner, K. N. (2010). Born to choose: the origins and value of the need for control. *Trends in Cognitive Sciences*, *14*(10), 457–463. https://doi.org/10.1016/j.tics.2010.08.001

Lessa, H. T., & Chiviacowsky, S. (2015). Self-controlled practice benefits motor learning in older adults. *Human Movement Science*, *40*, 372–380. https://doi.org/10.1016/j.humov.2015.01.013

Levin, M. F. (1996). Interjoint coordination during pointing movements is disrupted in spastic hemiparesis. *Brain: A Journal of Neurology*, *119*(1), 281–293. https://doi.org/10.1093/brain/119.1.281

Levin, M. F., & Demers, M. (2021). Motor learning in neurological rehabilitation. *Disability and Rehabilitation*, *43*(24), 3445–3453. https://doi.org/10.1080/09638288.2020.1752317

Lewthwaite, R., Chiviacowsky, S., Drews, R., & Wulf, G. (2015). Choose to move: the motivational impact of autonomy support on motor learning. *Psychonomic Bulletin & Review*, *22*(5), 1383–1388. https://doi.org/10.3758/s13423-015-0814-7

Lewthwaite, R., Winstein, C. J., Lane, C. J., Blanton, S., Wagenheim, B. R., Nelsen, M. A., Dromerick, A. W., & Wolf, S. L. (2018). Accelerating stroke recovery: body structures and functions, activities, participation, and quality of life outcomes from a large rehabilitation

trial. *Neurorehabilitation and Neural Repair*, *32*(2), 150–165. https://doi.org/10.1177/1545968318760726

Li, S., & Francisco, G. E. (2015). New insights into the pathophysiology of post-stroke spasticity. *Frontiers in Human Neuroscience*, *9*, 192. https://doi.org/10.3389/fnhum.2015.00192

Liew, S. L., Garrison, K. A., Ito, K. L., Heydari, P., Sobhani, M., Werner, J., Damasio, H., Winstein, C. J., & Aziz-Zadeh, L. (2018). Laterality of poststroke cortical motor activity during action observation is related to hemispheric dominance. *Neural Plasticity*, *2018*, 3524960. https://doi.org/10.1155/2018/3524960

Lin, F. M., & Sabbahi, M. (1999). Correlation of spasticity with hyperactive stretch reflexes and motor dysfunction in hemiplegia. *Archives of Physical Medicine and Rehabilitation*, *80*(5), 526–530. http://www.ncbi.nlm.nih.gov/pubmed/10326915

Lin, K., Chuang, L., Wu, C., Hsieh, Y., & Chang, W. (2010). Responsiveness and validity of three dexterous function measures in stroke rehabilitation. *Journal of Rehabilitation Research and Development*, *47*(6), 563–571. https://doi.org/10.1682/jrrd.2009.09.0155

Ly, V., Wang, K. S., Bhanji, J., & Delgado, M. R. (2019). A reward-based framework of perceived control. *Frontiers in Neuroscience*, *13*, 65. https://doi.org/10.3389/fnins.2019.00065

Magill, R. A., & Anderson, D. I. (2021). *Motor Learning and Control: Concepts and Applications* (12th ed.). McGraw-Hill.

Mahon, S., Faulkner, J., Barker-Collo, S., Krishnamurthi, R., Jones, K., & Feigin, V. (2020). Slowed information processing speed at four years poststroke: evidence and predictors from

a population-based follow-up study. *Journal of Stroke and Cerebrovascular Diseases*, *29*(2), 104513. https://doi.org/10.1016/j.jstrokecerebrovasdis.2019.104513

Maier, M., Ballester, B. R., & Verschure, P. F. M. J. (2019). Principles of neurorehabilitation after stroke based on motor learning and brain plasticity mechanisms. *Frontiers in Systems Neuroscience*, *13*, 74. https://doi.org/10.3389/fnsys.2019.00074

Mathiowetz, V., Volland, G., Kashman, N., & Weber, K. (1985). Adult norms for the Box and Block Test of manual dexterity. *The American Journal of Occupational Therapy*, *39*(6), 386–391. https://doi.org/10.5014/ajot.39.6.386

McAuley, E., Duncan, T., & Tammen, V. V. (1989). Psychometric properties of the Intrinsic Motivation Inventory in a competitive sport setting: a confirmatory factor analysis. *Research Quarterly for Exercise and Sport*, *60*(1), 48–58. https://doi.org/10.1080/02701367.1989.10607413

McEwen, S., Polatajko, H., Baum, C., Rios, J., Cirone, D., Doherty, M., & Wolf, T. (2015). Combined cognitive-strategy and task-specific training improve transfer to untrained activities in subacute stroke: an exploratory randomized controlled trial. *Neurorehabilitation and Neural Repair*, *29*(6), 526–536. https://doi.org/10.1177/1545968314558602

Meadmore, K. L., Hallewell, E., Freeman, C., & Hughes, A. M. (2019). Factors affecting rehabilitation and use of upper limb after stroke: views from healthcare professionals and stroke survivors. *Topics in Stroke Rehabilitation*, *26*(2), 94–100. https://doi.org/10.1080/10749357.2018.1544845

Murayama, K., Matsumoto, M., Izuma, K., & Matsumoto, K. (2010). Neural basis of the undermining effect of monetary reward on intrinsic motivation. *Proceedings of the National*

Academy of Sciences of the United States of America, *107*(49), 20911–20916. https://doi.org/10.1073/pnas.1013305107

Murayama, K., Matsumoto, M., Izuma, K., Sugiura, A., Ryan, R. M., Deci, E. L., & Matsumoto, K. (2015). How self-determined choice facilitates performance: a key role of the ventromedial prefrontal cortex. *Cerebral Cortex*, *25*(5), 1241–1251. https://doi.org/10.1093/cercor/bht317

Newell, K. M. (1985). Coordination, Control and Skill. In D. Goodman, R. B. Wilberg, & I. M. Franks (Eds.), *Differing Perspectives in Motor Learning, Memory, and Control* (pp. 295–317). Elsevier Science. https://doi.org/10.1016/S0166-4115(08)62541-8

Pathania, A., Leiker, A. M., Euler, M., Miller, M. W., & Lohse, K. R. (2019). Challenge, motivation, and effort: neural and behavioral correlates of self-control of difficulty during practice. *Biological Psychology*, *141*, 52–63. https://doi.org/10.1016/j.biopsycho.2019.01.001

Perse, E. M. (2009). Self-Assessment Manikin. In R. B. Rubin, A. M. Rubin, E. E. Graham, E. M. Perse, & D. Seibold (Eds.), *Communication Research Measures II* (1st ed., pp. 336–341). Routledge. https://doi.org/10.4324/9780203871539

Plautz, E. J., Milliken, G. W., & Nudo, R. J. (2000). Effects of repetitive motor training on movement representations in adult squirrel monkeys: role of use versus learning. *Neurobiology of Learning and Memory*, *74*(1), 27–55. https://doi.org/10.1006/nlme.1999.3934

Post, P. G., Fairbrother, J. T., & Barros, J. A. C. (2011). Self-controlled amount of practice benefits learning of a motor skill. *Research Quarterly for Exercise and Sport*, *82*(3), 474–481. https://doi.org/10.1080/02701367.2011.10599780

Prion, S., & Haerling, K. A. (2014). Making sense of methods and measurement: Spearman-rho ranked-order correlation coefficient. *Clinical Simulation in Nursing*, *10*(10), 535–536. https://doi.org/10.1016/j.ecns.2014.07.005

Quattrocchi, G., Greenwood, R., Rothwell, J. C., Galea, J. M., & Bestmann, S. (2017). Reward and punishment enhance motor adaptation in stroke. *Journal of Neurology, Neurosurgery, and Psychiatry*, *88*(9), 730–736. https://doi.org/10.1136/jnnp-2016-314728

Raghavan, P. (2015). Upper limb motor impairment after stroke. *Physical Medicine and Rehabilitation Clinics of North America*, *26*(4), 599–610. https://doi.org/10.1016/j.pmr.2015.06.008

Reutskaja, E., Lindner, A., Nagel, R., Andersen, R. A., & Camerer, C. F. (2018). Choice overload reduces neural signatures of choice set value in dorsal striatum and anterior cingulate cortex. *Nature Human Behaviour*, *2*(12), 925–935. https://doi.org/10.1038/s41562-018-0440-2

Reynolds, C. R. (2020). *Comprehensive Trail-Making Test* (2nd ed.). Pro-Ed.

Riccio, C. A., Blakely, A., Yoon, M., & Reynolds, C. R. (2013). Two-factor structure of the Comprehensive Trail-making Test in adults. *Applied Neuropsychology: Adult*, *20*(2), 155–158. https://doi.org/10.1080/09084282.2012.670169

Roby-Brami, A., Jarrassé, N., & Parry, R. (2021). Impairment and compensation in dexterous upper-limb function after stroke. From the direct consequences of pyramidal tract lesions to behavioral involvement of both upper-limbs in daily activities. *Frontiers in Human Neuroscience*, *15*, 662006. https://doi.org/10.3389/fnhum.2021.662006

Rohrbach, N., Chicklis, E., & Levac, D. E. (2019). What is the impact of user affect on motor learning in virtual environments after stroke? A scoping review. *Journal of Neuroengineering and Rehabilitation*, *16*(1), 79. https://doi.org/10.1186/s12984-019-0546-4

Rowe, J. B., Chan, V., Ingemanson, M. L., Cramer, S. C., Wolbrecht, E. T., & Reinkensmeyer, D. J. (2017). robotic assistance for training finger movement using a hebbian model: a randomized controlled trial. *Neurorehabilitation and Neural Repair*, *31*(8), 769–780. https://doi.org/10.1177/1545968317721975

Saes, M., Mohamed Refai, M. I., van Beijnum, B. J. F., Bussmann, J. B. J., Jansma, E. P., Veltink, P. H., Buurke, J. H., van Wegen, E. E. H., Meskers, C. G. M., Krakauer, J. W., & Kwakkel, G. (2022). Quantifying quality of reaching movements longitudinally post-stroke: a systematic review. *Neurorehabilitation and Neural Repair*, *36*(3), 183–207. https://doi.org/10.1177/15459683211062890

Sánchez, N., & Winstein, C. J. (2021). Lost in translation: simple steps in experimental design of neurorehabilitation-based research interventions to promote motor recovery post-stroke. *Frontiers in Human Neuroscience*, *15*, 644335. https://doi.org/10.3389/fnhum.2021.644335

Sanli, E. A., Patterson, J. T., Bray, S. R., & Lee, T. D. (2013). Understanding self-controlled motor learning protocols through the self-determination theory. *Frontiers in Psychology*, *3*, 611. https://doi.org/10.3389/fpsyg.2012.00611

Schaefer, S. Y., Patterson, C. B., & Lang, C. E. (2013). Transfer of training between distinct motor tasks after stroke. *Neurorehabilitation and Neural Repair*, *27*(7), 602–612. https://doi.org/10.1177/1545968313481279

Schambra, H. M., Parnandi, A., Pandit, N. G., Uddin, J., Wirtanen, A., & Nilsen, D. M. (2019). A taxonomy of functional upper extremity motion. *Frontiers in Neurology*, *10*, 857. https://doi.org/10.3389/fneur.2019.00857

Self-Determination Theory. (n.d.). *Intrinsic Motivation Inventory (IMI)*. https://selfdeterminationtheory.org/intrinsic-motivation-inventory/

Sinha, R., Lacadie, C. M., Constable, R. T., & Seo, D. (2016). Dynamic neural activity during stress signals resilient coping. *Proceedings of the National Academy of Sciences*, *113*(31), 8837–8842. https://doi.org/10.1073/pnas.1600965113

Sivrioglu, E. Y., Sivrioglu, K., Ertan, T., Ertan, F. S., Cankurtaran, E., Aki, O., Uluduz, D., Ince, B., & Kirli, S. (2009). Reliability and validity of the Geriatric Depression Scale in detection of poststroke minor depression. *Journal of Clinical and Experimental Neuropsychology*, *31*(8), 999–1006. https://doi.org/10.1080/13803390902776878

Speranza, L., di Porzio, U., Viggiano, D., de Donato, A., & Volpicelli, F. (2021). Dopamine: the neuromodulator of long-term synaptic plasticity, reward and movement control. *Cells*, *10*(4), 735. https://doi.org/10.3390/cells10040735

Subramanian, S. K., Feldman, A. G., & Levin, M. F. (2018). Spasticity may obscure motor learning ability after stroke. *Journal of Neurophysiology*, *119*(1), 5–20. https://doi.org/10.1152/jn.00362.2017

Taub, E., & Wolf, S. L. (1997). Constraint induced movement techniques to facilitate upper extremity use in stroke patients. *Topics in Stroke Rehabilitation*, *3*(4), 38–61. https://doi.org/10.1080/10749357.1997.11754128

Tomita, Y., Rodrigues, M. R. M., & Levin, M. F. (2017). Upper limb coordination in individuals with stroke: poorly defined and poorly quantified. *Neurorehabilitation and Neural Repair*, *31*(10–11), 885–897. https://doi.org/10.1177/1545968317739998

Verrienti, G., Raccagni, C., Lombardozzi, G., De Bartolo, D., & Iosa, M. (2023). Motivation as a measurable outcome in stroke rehabilitation: a systematic review of the literature. *International Journal of Environmental Research and Public Health*, *20*(5), 4187. https://doi.org/10.3390/ijerph20054187

Virani, S. S., Alonso, A., Aparicio, H. J., Benjamin, E. J., Bittencourt, M. S., Callaway, C. W., Carson, A. P., Chamberlain, A. M., Cheng, S., Delling, F. N., Elkind, M. S. V., Evenson, K. R., Ferguson, J. F., Gupta, D. K., Khan, S. S., Kissela, B. M., Knutson, K. L., Lee, C. D., Lewis, T. T., … Tsao, C. W. (2021). Heart disease and stroke statistics-2021 update: a report from the American Heart Association. *Circulation*, *143*(8), e254–e743. https://doi.org/10.1161/CIR.0000000000000950

Widmer, M., Held, J. P. O., Wittmann, F., Valladares, B., Lambercy, O., Sturzenegger, C., Palla, A., Lutz, K., & Luft, A. R. (2022). Reward during arm training improves impairment and activity after stroke: a randomized controlled trial. *Neurorehabilitation and Neural Repair*, *36*(2), 140–150. https://doi.org/10.1177/15459683211062898

Widmer, M., Lutz, K., & Luft, A. R. (2019). Reduced striatal activation in response to rewarding motor performance feedback after stroke. *NeuroImage. Clinical*, *24*, 102036. https://doi.org/10.1016/j.nicl.2019.102036

Winstein, C. J., Stein, J., Arena, R., Bates, B., Cherney, L. R., Cramer, S. C., Deruyter, F., Eng, J. J., Fisher, B., Harvey, R. L., Lang, C. E., MacKay-Lyons, M., Ottenbacher, K. J., Pugh, S., Reeves, M. J., Richards, L. G., Stiers, W., & Zorowitz, R. D. (2016a). Guidelines for

adult stroke rehabilitation and recovery: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*, *47*(6), e98–e169. https://doi.org/10.1161/STR.0000000000000098

Winstein, C. J., Wolf, S. L., Dromerick, A. W., Lane, C. J., Nelsen, M. A., Lewthwaite, R., Cen, S. Y., & Azen, S. P. (2016b). Effect of a task-oriented rehabilitation program on upper extremity recovery following motor stroke: the ICARE randomized clinical trial. *JAMA*, *315*(6), 571–581. https://doi.org/10.1001/jama.2016.0276

Winstein, C., Lewthwaite, R., Blanton, S. R., Wolf, L. B., & Wishart, L. (2014). Infusing motor learning research into neurorehabilitation practice: a historical perspective with case exemplar from the accelerated skill acquisition program. *Journal of Neurologic Physical Therapy*, *38*(3), 190–200. https://doi.org/10.1097/NPT.0000000000000046

Winstein, C., & Varghese, R. (2018). Been there, done that, so what's next for arm and hand rehabilitation in stroke? *NeuroRehabilitation*, *43*(1), 3–18. https://doi.org/10.3233/NRE-172412

Winterbottom, L., & Nilsen, D. M. (2024). Motor learning following stroke: mechanisms of learning and techniques to augment neuroplasticity. *Physical medicine and rehabilitation clinics of North America*, *35*(2), 277–291. https://doi.org/10.1016/j.pmr.2023.06.004

Wu, W. F. W., & Magill, R. A. (2011). Allowing learners to choose: self-controlled practice schedules for learning multiple movement patterns. *Research Quarterly for Exercise and Sport*, *82*(3), 449–457. https://doi.org/10.1080/02701367.2011.10599777

Wulf, G., & Adams, N. (2014). Small choices can enhance balance learning. *Human Movement Science*, *38*, 235–240. https://doi.org/10.1016/j.humov.2014.10.007

Wulf, G., Iwatsuki, T., Machin, B., Kellogg, J., Copeland, C., & Lewthwaite, R. (2018). Lassoing skill through learner choice. *Journal of Motor Behavior*, *50*(3), 285–292. https://doi.org/10.1080/00222895.2017.1341378

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review*, *23*(5), 1382–1414. https://doi.org/10.3758/s13423-015-0999-9

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V., Adey, M., & Leirer, V. O. (1982). Development and validation of a geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research*, *17*(1), 37–49. https://doi.org/10.1016/0022-3956(82)90033-4

Zilcha-Mano, S., & Webb, C. A. (2021). Disentangling trait-like between-individual vs. state-like within-individual effects in studying the mechanisms of change in CBT. *Frontiers in Psychiatry*, *11*, 609585. https://doi.org/10.3389/fpsyt.2020.609585

Appendix A: Blinded Assessor Manual

General Guidelines:

- The participants do not know the specific purpose of the study or the difference between groups. Please do not discuss this with them.
- You are blinded to group allocation so make sure that participants do not discuss what they did during the study with you.
- Please try to keep conversation to a minimum and avoid giving any feedback that is not scripted. However, any issues that a participant may be having (discomfort, fatigue, etc.) can always be addressed to make sure they are comfortable.
- When administering the assessments, please check the positioning of the participant first to make sure it is consistent (table height, chair position, etc.) Make sure to check off the items on the checklists.
- Please use the scripts as much as possible when administering the assessments. However, if someone does not understand something you can explain it as long as it stays within the procedures.
- Make sure that the assessments are administered in the same order as listed below.

Assessment Overview:

Day 1: Pre-Test (before training)

1. Self-Assessment Manikin
2. Scooping Task
    a. Stronger Arm: 1 block, 2 trials
    b. Weaker Arm: 1 block, 5 trials
3. mBBT
    a. Stronger Arm: 1 block, 2 trials
    b. Weaker Arm: 1 block, 5 trials

Day 2: Post-Assessments (after training)

1. Self-Assessment Manikin
2. Scooping Task Appraisal Scale
3. Intrinsic Motivation Inventory
4. mBBT (need to determine # of minutes after completion of training)
    a. Stronger Arm: 2 blocks, 2 trials
    b. Weaker Arm: 2 blocks, 5 trials

Day 3: Follow-up Assessments

1. Self-Assessment Manikin
2. Scooping Task Appraisal Scale
3. Scooping Task
    a. Stronger Arm: 2 blocks, 2 trials
    b. Weaker Arm: 2 blocks, 5 trials
4. mBBT
    a. Stronger Arm: 2 blocks, 2 trials
    b. Weaker Arm: 2 blocks, 5 trials

Scooping Task.
Adapted from Schaefer et al. (2013).

Participant Positioning Requirements (Please check off)

- ❑ Line up the dot on the board with the participant's axilla crease and edge of table
- ❑ Stabilize the board with a weight placed between the two cups
- ❑ Participant's back is supported by the chair, and the chair is pulled up to the table
- ❑ The participant's feet are flat on floor
- ❑ Adjust table height so that *the elbow at 90-degree angle* when resting on table
- ❑ Table height adjusted to _____ cm from floor to the *bottom edge* of the table (must be the same height for all visits)
- ❑ Hand that is not being testing is in the participant's lap
- ❑ Hand being tested is holding the spoon, resting on the table next to the cup
- ❑ Seat Cushion *(optional – use only if needed for participant's comfort)*

Participant Instructions:

"I want to see how quickly you can scoop beans with your right (or left) hand [point to the stronger hand]. Use the spoon to transfer them to the other cup. You must transfer one or more beans for a scoop to be counted. The number of beans you scoop does not matter as long as you transfer at least one, so do not worry about the number of beans on your spoon. Your goal is to complete as many scoops as you can, not to empty the cup, so small scoops are okay. If any beans fall on the floor or table, do not waste time picking them up. Just keep going. If all the beans fall, then start again."

- *Quickly* transport three scoops of beans (2-3 beans per scoop) using the spoon.
- After correct demonstration, show that if they drop all beans they should start again, and then drop only one but keep going (demonstrate the differences and discuss).

After a demonstration say the following:
"Now you will have a chance to practice for 15 seconds. Do you have any questions?"
"Hold the spoon with a comfortable grip and rest your hand on the table next to the cup closest to you. Place your other hand in your lap. When it is time to start, I will say:
"Ready, Set, Go."

- Say one word per second.
- Start stopwatch at "Go" and stop after 15 seconds.
- If mistakes are made during the practice period, correct them before the actual testing.

Trial period:
"Ready, Set, *Go." [After 15 seconds]. "Stop."* [Return the transported beans to the original cup. Correct any mistakes that were made.]

Actual test:
"This will be the actual test, which will be 30 seconds. We will do 2 trials. The instructions are the same. Work as quickly as you can."
"Ready, Set, *Go." [30 seconds] "Stop."* [Count the number of completed scoops using the clicker while the participant is scooping the beans. Record the number on the score form.]
"*Trial 1 is complete. Now we will move on to trial 2. The instructions are the same. Work as quickly as you can."*
"Ready, Set, *Go." [30 seconds] "Stop."* [Record the number on the score form.]

[Move the apparatus to line up with the participant's axilla crease of the weaker arm and edge of the table.]

"Now you are to do the same thing with your left (or right) hand [point to weaker hand]. We will do 5 trials. First you can practice. Hold the spoon with a comfortable grip and rest your hand on the table next to the cup closest to you as before. Place your other hand in your lap. Use the spoon to scoop beans and transfer them to the other cup."

Trial period:
"Ready, Set, *Go."* [After 15 seconds] *"Stop."*

Actual test:
"This will be the actual test, which will be 30 seconds. The instructions are the same. Work as quickly as you can."
*** *"Ready,* Set, *Go." [30 seconds] "Stop."* [Count the number of completed scoops and record.]
"Trial 1 is complete. Now we will move on to trial 2. The instructions are the same. Work as quickly as you can." [Repeat this script from *** for trials 3-5.]

Modified Box and Block Test.
Adapted from Schaefer et al. (2013) and Mathiowetz et al. (1985).

Participant Positioning Requirements (Please check off)

- ❑ Box is stabilized with Dycem in an anterior-posterior position
- ❑ Box is centered with the participant's trunk and lined up with the edge of the table
- ❑ Hand that is not being testing is in the participant's lap
- ❑ Hand that is being tested is resting on the table next to the box
- ❑ Seat Cushion *(optional – use only if needed for participant's comfort)*

Participant Instructions

"I want to see how quickly you can pick up one block at a time with your right (or left) hand [point to the stronger hand]. Carry it across the partition to the other side of the box and drop it. Make sure your fingertips cross the partition, and make sure not to throw the block over the partition. If you pick up two blocks at a time, they will count as one. If you drop a block on the floor or table, just keep going. Don't waste time picking it up. If a block bounces out of the box after you have carried it across, it will still be counted. If you toss the blocks without your fingertips crossing the partition, they will not be counted. Watch me while I show you how."

- *Quickly* transport three cubes over the partition in the same direction you want the participant to move them.
- After correct demonstration, show that if they toss the blocks without crossing the partition it will not count, and if they transport 2 blocks, it will count as one.

After a demonstration say the following:

"Now you will have a chance to practice for 15 seconds. Do you have any questions?"
"Place this hand [point to weaker hand] in your lap. Place this hand [point to stronger hand] on the table next to the box. When it is time to start, I will say:
"Ready, Set, Go."

- Say one word per second.
- Start stopwatch at "Go" and stop after 15 seconds.
- If mistakes are made during the practice period, correct them before the actual testing

Trial period:

"Ready, Set, Go." [After 15 seconds] *"Stop."*
[Return the transported blocks to the original compartment. Correct any mistakes that were made.]

Actual test:
"This will be the actual test, which will be 30 seconds. We will do 2 trials. The instructions are the same. Work as quickly as you can."
"Ready, Set, Go." [30 seconds] *"Stop."* [Count the number of transported blocks and record.]
"*Trial 1 is complete. Now we will move on to trial 2. The instructions are the same. Work as quickly as you can."*
"Ready, Set, *Go." [30 seconds] "Stop."* [Record the number on the score form.]

"Now you are to do the same thing with your left (or right) hand [point to weaker hand]. We will do 5 trials. First you can practice. Put this hand [point to stronger hand] in your lap. Place this hand [point to weaker hand] on the table next to the box. Pick up one block at a time with your hand, and drop it on the other side of the box."

Trial period:
"Ready, Set, Go." [After 15 seconds] *"Stop."*

Actual test:
"This will be the actual test, which will be 30 seconds. The instructions are the same. Work as quickly as you can."
*** *"Ready,* Set, *Go." [30 seconds] "Stop."* [Count the number of completed scoops and record.]
"Trial 1 is complete. Now we will move on to trial 2. The instructions are the same. Work as quickly as you can." [Repeat this script from *** for trials 3-5.]

Note. Instructions are adapted from the original Box and Block Test instructions (Mathiowetz et al., 1985, p. 388).

Appendix B: Self-Assessment Manikin (SAM)

Self-Assessment Manikin: Please mark the circle that best describes your mood right now.

(Image of the valance subscale can be found in Bradley and Lang, 1994, p. 51).

Appendix C: Scooping Task Appraisal Scale (STAS)

Scooping Task Appraisal Scale: If you were asked how many scoops of beans you could transfer in 30 seconds right now, how certain are you that you can complete the numbers described below? Rate your degree of confidence by recording a number from 0 (not confident at all) to 10 (very confident) using the scale given below. Adapted from Bandura (2006).

Appendix D: Intrinsic Motivation Inventory (IMI)

The Intrinsic Motivation Inventory can be retrieved from https://selfdeterminationtheory.org/intrinsic-motivation-inventory/ (Self-Determination Theory, n.d.). The 28-item version of the instrument that was used in this study includes items from each of the six subscales (interest/enjoyment – 7 items; perceived competence – 5 items; perceived choice – 5 items; pressure/tension – 5 items; value/usefulness – 3 items; effort/importance – 3 items). Twenty-two of the items were taken from a version of the IMI called the Task Evaluation Questionnaire, which uses four of the six subscales (interest/enjoyment, perceived competence, pressure/tension, perceived choice; Self-Determination Theory, n.d.). The remaining six questions were added to represent effort/importance and value/usefulness subscales based on an instrument used by Rowe and colleagues (2017). Responses are rated on a 7-point Likert scale. All items in each subscale are then averaged to determine a score for the subscale.

Appendix E: Intervention Script

Day 1 Script:

Thank you for completing the assessments. Now we will move on to the practice portion of the study. For this part of the study, I will be using a script and will ask that we keep our conversation to a minimum. However, if you need a break or have any discomfort, please let me know, and we will pause to address anything you may need.

The practice sessions today and tomorrow will involve practicing the Scooping Task that you just completed. You will practice sets of trials using each of your arms. Repetitive practice of a motor skill can help improve that skill and may also transfer to other skills. Practicing with your right/left (stronger) arm may also help to improve your performance with your right/left (weaker) arm.

When practicing with your right/left (stronger) arm, you will complete two 30-second trials for each set. When practicing with your right/left (weaker) arm, you will complete five 30-second trials for each set. You will practice 10 sets with each of your arms for a total of 20 sets today. The same sets will be repeated tomorrow.

GROUP A: I have set out 20 cards on the table – 10 for practicing with your right/left (stronger) arm, and 10 for practicing with your right/left (weaker) arm. Before each set, I will select a card that will indicate which arm you will use. The cards will help us keep track of how many sets you have done with each arm. Do you have any questions?

GROUP B: I have set out 20 cards on the table – 10 for practicing with your right/left (stronger) arm, and 10 for practicing with your right/left (weaker) arm. You can choose when you practice each set. You can choose any order that you would like. For example, when you want to practice with your right arm, you would choose this card [demonstrate selecting card for right arm], and when you want to practice with my left arm, you would choose this card [demonstrate selecting card for left arm]. Continue to choose the cards until they are all gone, and you have completed all 20 sets. Choose one card at a time. The cards will help us keep track of how many sets you have done with each arm. Do you have any questions?

As a reminder, the goal of this task is to see how quickly you can scoop beans with each of your hands using a spoon to transfer them to the other cup. You must transfer one or more beans for a scoop to be counted. The number of beans you scoop does not matter as long as you transfer at least one, so do not worry about the number of beans on your spoon. Your goal is to complete as many scoops as you can, not to empty the cup, so small scoops are okay. If any beans fall on the floor or table, do not waste time picking them up. Just keep going. If all the beans fall, then start again.

GROUP A: Now, I will select the card you will start with. [Researcher selects card]. You will complete the first trial using your right/left hand.

GROUP B: Now, choose the card from the side you would like to practice. [Participant selects card.] You chose to practice using your right/left hand for this trial.

[The apparatus is set-up for the first trial.]

Hold the spoon with a comfortable grip and rest your hand on the table next to the cup closest to you. Place your other hand in your lap. While you are practicing, feel free to adjust your grip to find whatever is most comfortable for you. At the end of each set, I will let you know the high score and the low score of the set.

When it is time to start, I will say:

"Ready, Set, Go."

Do you have any questions?

This is the first set. We will do 2/5 trials. Each trial will be 30 seconds. The instructions are the same as before. Work as quickly as you can.

Ready, Set, Go. [Continue for 2 trials with the stronger hand or 5 trials with the weaker hand until the block is completed.]

Great job. The first set is over.

[When practicing with the weaker arm:] Your high score for this set was ____ and your low score was ____.

Now we will move on to the second set. [Repeat for 20 total blocks: 10 blocks for the stronger arm and 10 blocks for the weaker arm.]

[After completion of all the trials.]

Thank you so much for your hard work today. Your high score for the day was ____ and your low score was ____.

Day 2 Script:

Today will involve practicing the same task that you practiced yesterday.

As a reminder, you will practice sets of trials using each of your arms. Repetitive practice of a motor skill can help improve that skill and may also transfer to other skills. Practicing with your right/left (stronger) arm may also help to improve your performance with your right/left (weaker) arm.

You will complete the same number of sets with each of your arms that you completed yesterday.

GROUP A: I have set out 20 cards on the table – 10 for practicing with your right/left (stronger) arm, and 10 for practicing with your right/left (weaker) arm. Before each set, I will select a card that will indicate which arm you will use. The cards will help us keep track of how many sets you have done with each arm. Do you have any questions?

GROUP B: I have set out 20 cards on the table – 10 for practicing with your right/left (stronger) arm, and 10 for practicing with your right/left (weaker) arm. You can choose when you practice each set. You can choose any order that you would like. For example, when you want to practice with your right arm, you would choose this card [demonstrate selecting card for right arm], and when you want to practice with my left arm, you would choose this card [demonstrate selecting card for left arm]. Continue to choose the cards until they are all gone, and you have completed all 20 sets. Choose one card at a time. The cards will help us keep track of how many sets you have done with each arm. Do you have any questions?

As a reminder, the goal of this task is to see how quickly you can scoop beans with each of your hands using a spoon to transfer them to the other cup. You must transfer one or more beans for a scoop to be counted. The number of beans you scoop does not matter as long as you transfer at least one, so do not worry about the number of beans on your spoon. Your goal is to complete as many scoops as you can, not to empty the cup, so small scoops are okay. If any beans fall on the floor or table, do not waste time picking them up. Just keep going. If all the beans fall, then start again.

GROUP A: Now, I will select the card you will start with. [Researcher selects card]. You will complete the first trial using your right/left hand.

GROUP B: Now, choose the card from the side you would like to practice. [Participant selects card.] You chose to practice using your right/left hand for this trial.

[The apparatus is set-up for the first trial.]

Hold the spoon with a comfortable grip and rest your hand on the table next to the cup closest to you. Place your other hand in your lap. While you are practicing, feel free to adjust your grip to find whatever is most comfortable for you. At the end of each set, I will let you know the high score and the low score of the set.

When it is time to start, I will say:

"Ready, Set, Go."

Do you have any questions?

This is the first set. We will do 2/5 trials. Each trial will be 30 seconds. The instructions are the same as before. Work as quickly as you can.

Ready, Set, Go. [Continue for 2 trials with the stronger hand or 5 trials with the weaker hand until the block is completed.]

Great job. The first set is over.

[When practicing with the weaker arm:] Your high score for this set was ____ and your low score was ____.

Now we will move on to the second set. [Repeat for 20 total blocks: 10 blocks for the stronger arm and 10 blocks for the weaker arm.]

[After completion of all the trials.]

Thank you so much for your hard work today. Your high score for the day was ____ and your low score was ____.

Appendix F: Pilot Study Results

Participant Characteristics

A total of seven participants have consented to participate in the study. One participant failed the screening, so six participants were accrued. Once two participants were accrued within a BBT strata, they were then randomized to either experimental or control groups. Three subjects were randomized into each group. See Table 1 for individual participant characteristics. See Table 2 for baseline assessment results for individual participants. Table 3 summarizes group results for participant characteristics and results of baseline assessments.

Outcomes Measures

Participants in the experimental group chose the order in which they practiced blocks of trials with their more and less affected hands. The order in which individuals in the experimental group made these choices is depicted in Figure 1. Results of individual performance across all blocks of the Scooping Task can be visualized in Figure 2, including the Pre-Test, the Practice Phase, and the Retention Test. Figure 3 depicts group performance on the Scooping Task on the Retention Test. Individual performance across all blocks of the modified Box and Block Test, including the Pre-Test, the Immediate (10-minute) Transfer Test, and the Delayed (24-Hour) Transfer Test can be viewed in Figure 4, while group performance is shown in Figure 5. Group means and standard deviations for all outcome measures can be viewed in Tables 4-7.

Table 1

Individual participant characteristics

Participant	Age	Gender	Race	Months since Stroke	Type of Stroke	Affected Side	Dominant Side
Experimental							
003	53	M	White	88	Ischemic	Left	Right
005	55	M	White	106	Hemorrhagic	Left	Right
006	53	M	White	527	Ischemic	Right	Right
Control							
001	65	F	Black	143	Ischemic	Left	Left
004	56	F	Multiple	78	Ischemic	Left	Right
007	65	M	White	193	Hemorrhagic	Left	Right

Note. M = male; F = female.

Table 2

Baseline assessment for individual participants

Participant	BBT	SCI	GDS	CTMT-2 TCI T-Score (Description)	MAS (EF)
Experimental					
003	36	32	1	41 (Below Average)	1+
005	40	28	4	31 (Mild-Mod Impairment)	1+
006	27	28	0	63 (High Average)	1+
Control					
001	33	26	4	35 (Mild-Mod Impairment)	1
004	44	12	2	42 (Below Average)	0
007	40	32	1	47 (Average)	1

Note. BBT = Box and Block Test; SCI = Sleep Condition Indicator; GDS = Geriatric Depression Scale; CTMT-2 TCI = Comprehensive Trail-Making Test, Second Edition, Total Composite Index; MAS (EF) = Modified Ashworth Scale (elbow flexors).

Table 3

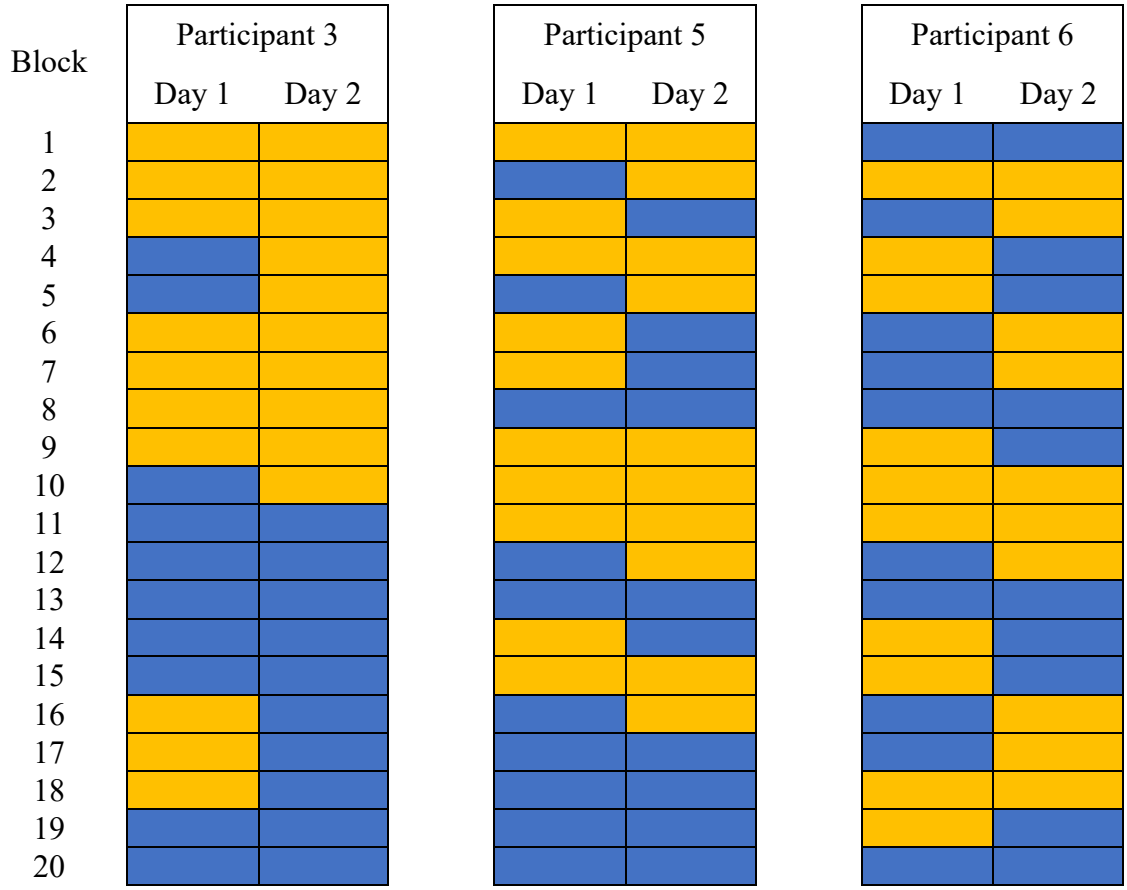
Summary of participant characteristics and baseline assessment

Characteristics	Experimental (n=3)	Control (n=3)	Total (N=6)
Age in years, mean (SD)	53.7 (1.2)	62.0 (5.2)	57.8 (5.7)
Gender	3 M/ 0 F	1 M/ 2 F	4 M / 2 F
Race	3 White	Black, Multiple, White	Black, Multiple, 4 White
Months since stroke, mean (SD)	240.3 (248.4)	138.0 (57.7)	189.2 (170.8)
Type of stroke	2 Ischemic/ 1 Hemorrhagic	2 Ischemic/ 1 Hemorrhagic	4 Ischemic/ 2 Hemorrhagic
Affected side	2 Left/ 1 Right	3 Left/ 0 Right	5 Left/ 1 Right
Dominant side affected?	1 Yes/ 2 No	1 Yes/ 2 No	2 Yes/ 4 No
BBT Score, mean (SD)	34.2 (6.7)	39.0 (5.6)	36.7 (6.1)
SCI, mean (SD)	29.3 (2.3)	23.3 (10.3)	26.3 (7.4)
GDS, mean (SD)	1.7 (2.1)	2.3 (1.5)	2.0 (1.7)
CTMT-2 TCI, mean (SD)	45.0 (16.4)	41.3 (6.0)	43.2 (11.2)
MAS elbow flexors, n (score)	3 (1+)	1 (0), 2 (1)	1 (0), 2 (1), 3 (1+)

Note. M = male; F = female; BBT = Box and Block Test; SCI = Sleep Condition Indicator; GDS = Geriatric Depression Scale; CTMT-2 TCI = Comprehensive Trail-Making Test, Second Edition, Total Composite Index; MAS = Modified Ashworth Scale.

Figure 1

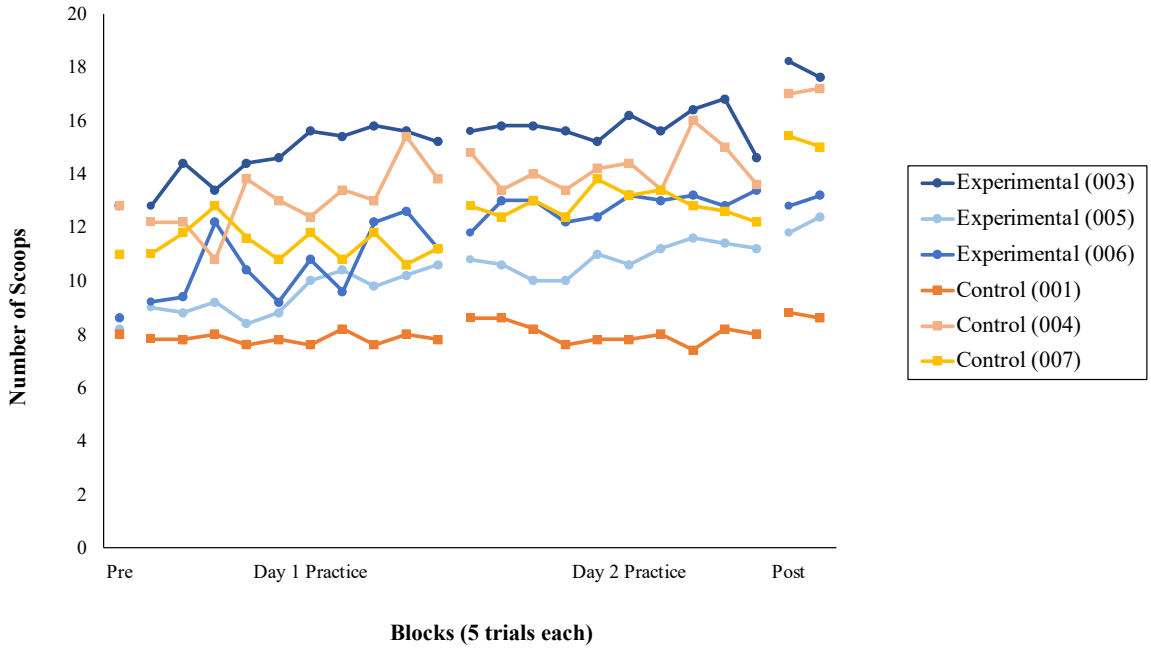
Order of choices made by experimental group participants



Note. The figure demonstrates the order of blocks that were chosen by the experimental group. Blue cells indicate blocks of 2 trials that were performed with the less affected arm. Yellow cells indicate blocks of 5 trials with were performance with the more affected arm.

Figure 2

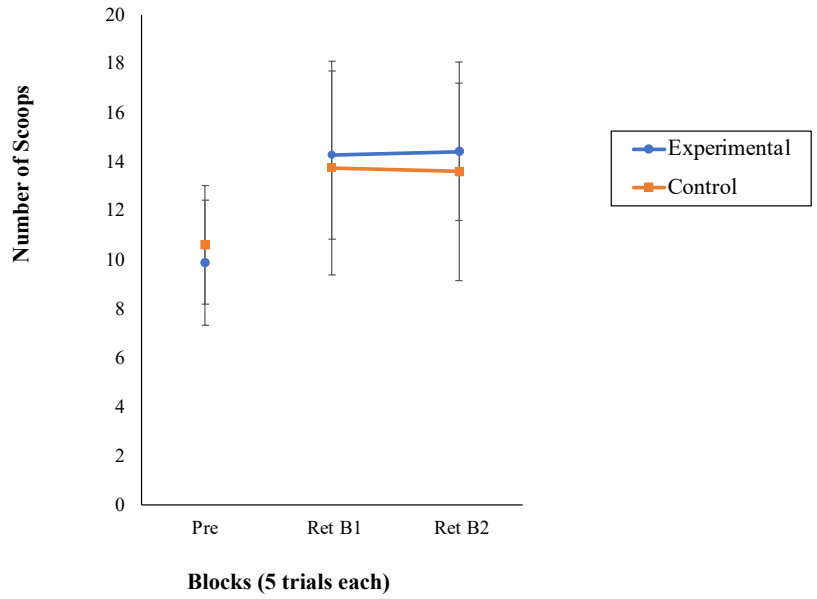
Individual Performance on the Scooping Task



Note. This figure demonstrates individual performance on the scooping task with the more affected arm at Pre-Test (Day 1), during the Practice Phase (Day 1, Day 2), and at the 24-Hour Retention Test (Day 3). Means for each block of 5 trials are shown with error bars indicating the standard deviation. Performance of experimental group participants is represented by blue lines with round markers, and performance of control group participants is represented by orange lines with square markers.

Figure 3

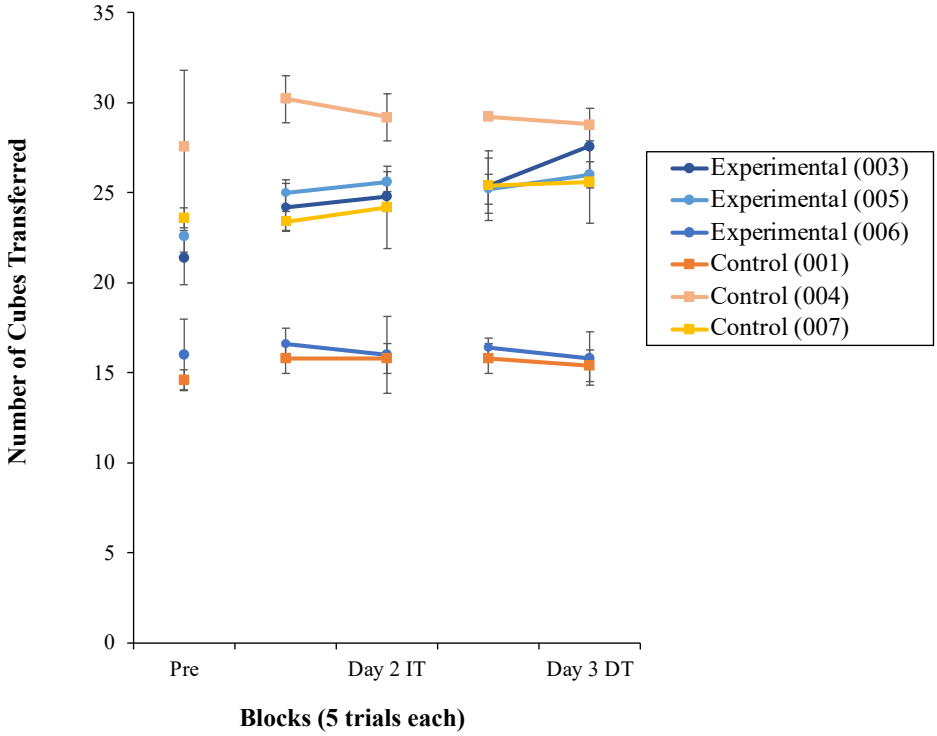
Group Performance on Retention of the Scooping Task



Note. This figure demonstrates group performance on the scooping task with the more affected arm at the 24-Hour Retention Test (Day 3). Means for each block of 5 trials are shown with error bars indicating the standard deviation. Pre = pre-test; Ret = retention; B1 = block 1; B2 = block 2.

Figure 4

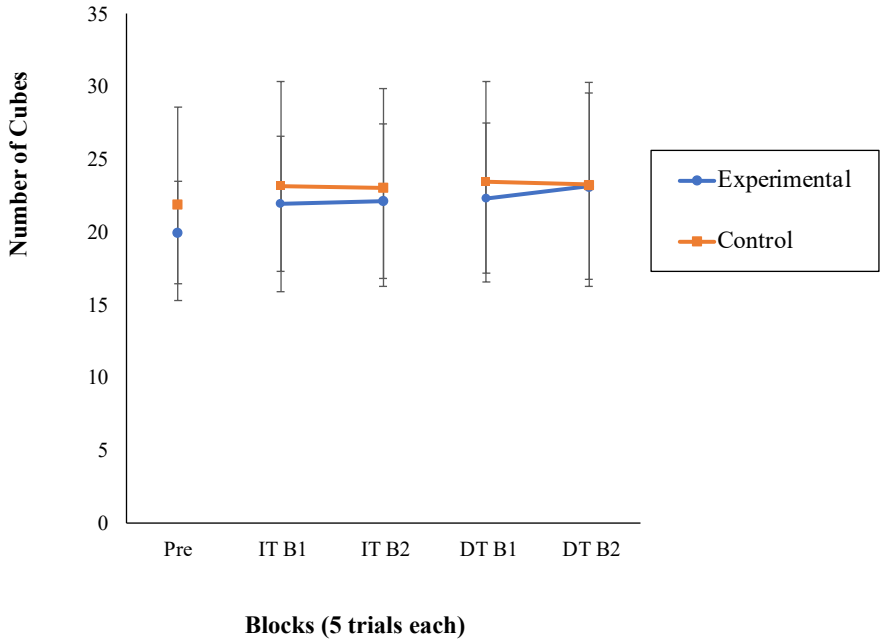
Individual Performance on the Modified Box and Block Test



Note. This figure demonstrates individual performance on the modified Box and Block Test with the more affected arm at Pre-Test (Day 1), Immediate (10-minute) Transfer Test (Day 2), and at the Delayed (24-Hour) Transfer Test (Day 3). Means for each block of 5 trials are shown with error bars indicating the standard deviation. Performance of experimental group participants is represented by blue lines with round markers, and performance of control group participants is represented by orange lines with square markers. IT = immediate transfer; DT = delayed transfer.

Figure 5

Group Performance on Immediate and Delayed Transfer of the Modified Box and Block Test



Note. This figure demonstrates group performance on the modified Box and Block Test with the more affected arm at the Immediate (10-minute) Transfer Test on Day 2 and the Delayed (24-Hour) Transfer Test on Day 3. Means for each block of 5 trials are shown with error bars indicating the standard deviation. Pre = pre-test; IT = immediate transfer; DT = delayed transfer; B1 = block 1; B2 = block 2.

Table 4

Motor Learning Outcomes for the Scooping Task and mBBT

Motor Learning Outcomes	Experimental (n=3)	Control (n=3)
Scooping Task		
Pre-Test	9.9 (2.5)	10.6 (2.4)
Retention Block 1	14.3 (3.4)	13.7 (4.3)
Retention Block 2	14.4 (2.8)	13.6 (4.5)
mBBT		
Pre-Test	20.0 (3.5)	21.9 (6.7)
IT Block 1	21.9 (4.6)	23.1 (7.2)
IT Block 2	22.1 (5.3)	23.1 (6.8)
DT Block 1	22.3 (5.1)	23.5 (6.9)
DT Block 2	23.1 (6.4)	23.3 (7.0)

Note. Group means (standard deviations) are reported for blocks of 5 trials. mBBT = modified Box and Block Test. IT = immediate (10-minute) transfer. DT = delayed (24-hour) transfer.

Table 5

Intrinsic Motivation Inventory Results

IMI Subscales	Experimental (n=3)	Control (n=3)
Interest/ Enjoyment	4.7 (1.9)	4.9 (1.8)
Perceived Competence	5.7 (0.4)	6.1 (0.8)
Perceived Choice	6.5 (0.6)	6.5 (0.4)
Pressure/ Tension	2.8 (0.9)	1.5 (0.9)
Value	5.8 (0.2)	6.6 (0.5)
Effort	5.1 (1.6)	6.5 (0.4)

Note. The Intrinsic Motivation Inventory can be found in Appendix D. Group means (standard deviations) are presented for each subscale. Higher scores indicate a greater degree of the construct being measured. For example, higher scores in Interest/ Enjoyment indicate greater interest and enjoyment (intrinsic motivation). Higher scores in Pressure/ Tension indicate more pressure and tension. IMI = Intrinsic Motivation Inventory. (Additional data will be added for the remaining participants once it is collected).

Table 6

Self-Efficacy for the Scooping Task

Self-Efficacy	Experimental (n=3)	Control (n=3)
Day 2 Post-Test		
Median	7.3 (3.8)	8.3 (2.9)
Max	4.3 (4.2)	7.0 (2.0)
Max Plus	3.0 (5.2)	4.0 (2.6)
Total Mean	4.9 (3.9)	6.4 (2.2)
Day 3 Follow-Up		
Median	7.0 (3.6)	8.3 (2.1)
Max	4.0 (2.6)	7.0 (2.0)
Max Plus	2.3 (3.2)	6.0 (1.7)
Total Mean	4.4 (2.8)	7.1 (1.9)

Note. The Scooping Task Appraisal Scale can be found in Appendix C. Group means (standard deviations) are reported for each rating. Participants are asked to rate their confidence for getting their median score, maximum score, and max-plus score [(max – median)/2 + max] from the combined two days of practice. The Total Mean score is the average of those three ratings. Higher scores indicate higher self-efficacy.

Table 7

Self-Assessment Manikin (Valence Subscale)

SAM	Experimental (n=3)	Control (n=3)
Day 1 Pre-Test	2.7 (2.1)	1.7 (1.2)
Day 2 Post-Test	2.3 (2.3)	2.3 (2.3)
Day 3 Follow-Up	2.3 (2.3)	1.7 (1.2)

Note. The Self-Assessment Manikin can be found in Appendix B. Lower scores indicate more positive affect. SAM = Self-Assessment Manikin.