MOTOR INFORMATION, BEHAVIOUR & LEARNING

THE ROLE OF MOTOR INFORMATION IN LEARNING AND BEHAVIOUR IN THE PRESENCE AND ABSENCE OF CHALLENEGE: PHYSICAL OR COGNITIVE

By
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ABSTRACT

There is a growing body of evidence to support the claim that motor information is perceived, stored and retrieved in a pathway separable from other sensory processes. Motor information has become particularly important, with recent evidence supporting possible sparing of the motor system in natural aging and disease. Studying the motor pathway independently furthers our understanding of motor information and its interaction with learning, enhancing our understanding of memory processing, retrieval and storage.

This thesis was specifically designed to explore the role of motor information in behavior and learning in the presence and absence of physical and cognitive challenges. The first experiment examined the role of motor information in the maintenance of standing balance. This study found that light touch (motor information) was most useful when visual condition was challenging, eyes closed. Increased benefit of touch in the presence of challenge suggests that motor information may provide similar information as other senses, and act in a compensatory fashion when those senses are challenged. The second study examined the role of motor information, in the form of enactment, in learning a motor communication task. Results from this study support a role for motor information in enriching the learning environment by strengthening memory to reduce rate of forgetting. The third study examined the role of motor information in disease, using motor-centric instruction and guided movements to teach persons with Alzheimer Dementia to bowl using the Nintendo Wii ™. The spared

motor learning observed in these participants confirms claims in the literature of spared motor function in persons with dementia and strengthens the claim the motor system can provide compensatory information to support challenged cognitive systems. Taken together, these findings add to the current literature supporting motor pathways with information separable form other sensory pathways and spared motor capacity to learn in dementia.

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Introduction

Motor information is studied to understand its role in control and learning from cellular to whole body systems, although it is a thin, grey line that separates the two functions. Motor information, can be defined strictly as memory for action (Engelkamp & Zimmer, 1984) or more broadly as physical information about the action as well as semantic and conceptual information about the movement (Masumoto, Yamaguchi, Sutani, Tsuneto, Fujita & Tonoike, 2006). For the purpose of this document, it is defined as memory for the action event – that information that regulates the unfolding of movement. This thesis will explore the role of motor information in motor control and learning through examination of these functions in the presence and absence of a challenge, either physical- or memory -related. This work will provide insight in the importance of motor information in relation to other sensory and cognitive processes in motor control and learning across the lifespan.

Literature Review

The following literature overview will discuss existing work in motor control, specifically related to manipulation of light touch to maintain/improve postural stability, and motor learning, examining the enactment effect and work involving expanded retrieval and errorless learning methods. This literature review will build support for the claim that motor memory inputs are separable

from other types of information and the implications of such a distinct, definable system on normal aging and disease.

Motor Control

In its strictest definition, motor control is the systematic transmission of nerve impulses from the primary motor cortex to motor units, resulting in coordinated contractions of muscles (Mosby, 2009). Many of the movements and motor actions we complete on a daily basis can be considered to be 'automatic', in the sense that they do not require conscious attention to be completed. Even consciously attended-to actions such as walking or using your index finger to scratch your nose, are activities that, for most cognitively healthy individuals, require little to no cognitive effort. In the absence of physical barriers to action completion, motor control occurs in a variety of ways without our conscious intervention. Balance, standing or sitting, relies on a number of motor control processes. These processes have been studied for the rehabilitation, maintenance and optimization of balance. Control operates on two main components in maintenance of static balance: a) roll, side-to-side movement, and b) pitch, forward and backward movement. A number of variables have been manipulated to examine their impact on postural stability, including visual information (Duarte, & Zatsiorsky, 2002), tactile feedback, cognitive distraction (via dual task), and stance difficulty (Strang et al., 2010). The variable of interest in this thesis is motor information. Examining the role of strictly motor information in postural control is the first step in understanding how and under what

conditions motor information is utilized, and whether this utilization is dependent on task difficulty. Once we understand the contribution of motor information to performance we can move on to explore its long-term role in learning, memory and retrieval.

Motor Learning

"Motor learning is a set of [internal] processes associated with practice or experience leading to relatively permanent changes in the capability for motor skill" (Schmidt & Lee, 2011). This definition captures the dynamism of motor learning, accurately incorporating the true impact of motor information on learning of skills. Learning has been examined across a multitude of tasks in order to form a general representation of the stages by which information is taken in, processed and made available for use. Understanding the stages of learning allows a deeper look at the types of information, methods of presentation and practice that may optimize our ability to learn and retain items.

One such model, the Fitts and Posner classic learning stages model (1967), breaks down learning into three stages: cognitive, associative, and autonomous. The cognitive stage involves the learner addressing the problem of motor control in terms of the cognitively oriented components of the task, such as what is the objective of the task? How to best interact with the objects required to complete the task? Performance in this stage is usually highly variable and errorful (Magill, 2010). Imaging studies have revealed that the neural correlates of this cognitive stage of learning include the cerebellum and striatum (Lindquist

& Guadagnoli, 2008). The cerebellum is the site of the integration and coupling of sensory and motor input during this stage, playing a key role in the development of the generalized motor program, as well as transfer of motor skills (Lindquist & Guadagnoli, 2008). Basal ganglia circuitry is also thought to be engaged in the cognitive stage of learning, specifically anterior associative/pre motor and posterior sensorimotor/BG loops, when working memory and cognitive strategies are utilized (Lindquist & Guadagnoli, 2008).

The associative stage involves the learner beginning to associate environmental cues with movements required to achieve a desired performance. This is a refining stage – number and size of errors decreases and performance becomes more consistent. In this stage there is a dramatic decrease in cerebellar activity, and an increase in the parieto-temporal and occipitotemporal association areas, a shift that may support elimination of performance errors (Lindquist & Guadagnoli, 2008). Activation in these areas has been related to spontaneous generation of learned motor sequences (Mitra, Bhalerao, Summers, & Williams, 2005).

The third stage is the autonomous stage, which is the result of a high volume of practice and experience with the skill. Not all learners reach this stage, as it is a mark of expertise in a skill, where completing the skill becomes automatic. Attention demands in performing the task are severely reduced and successful multi-tasking can occur without detriment to performance (Magill, 2010). It is suggested that during this stage there is activation of desired motor

plan and inhibition of undesired plans happening concurrently (Lindquist & Guadagnoli, 2008). These actions are thought to engage the ventrolateral PFC, to regulate inhibition of undesired programs, which in turn increases inhibitory input to the caudate nucleus which plays a role in the successful control of perseveration (Lindquist & Guadagnoli, 2008).

In a healthy, cognitively functioning individual these three stages can accurately describe the learning and performance processes for many tasks. In persons with impaired cognition, however, these stages fail to accurately characterize the learning process. Since, the Fitts and Posner model is built on a cognitive understanding of the task to be completed, this model would immediately prevent persons with cognitive impairment from transitioning beyond stage one. The cognitive stage, a focus primarily on cognitive issues regarding a task, can be detrimental to engagement and learning in persons with impaired cognition, such as memory impairment and dementia. While addressing these questions can be useful, information related to why and how to complete a task must be stored externally in order to be utilized effectively by persons with memory impairments. Evidence from the enactment literature suggests that shifting focus from the cognitive, to more physical components of a task, may improve learning and memory, especially in the case of impaired cognition (Lekeu, Linden, Moonen & Salmon, 2002).

Once a general understanding of the stages that an individual traverses during the learning processes are established, the next step is to examine the

variable components of these stages. The variable components include content studied, learning environment, practice scheduling and error. Much attention has been paid to both the environment in which one learns and the amount of information presented, as well as examining the most effective methods and schedules with which to improve learning and memory in healthy and cognitively impaired populations (Lee, Swanson & Hall, 1991; Hochhalter, Overmier, Gasper, Bakke & Holub, 2005).

Content

Information can be categorized as relevant or irrelevant, depending on the choice-response nature of the task (Rabbitt, 1967). Relevant information, items that are directly related to the item(s) to be learned, can involve sensory information, as well as contextually related information. An example of relevant sensory information would be the sweet smell of a rose, when one is attempting to learn a list of flower types. Contextually relevant information could be words or items related to the word that the participant is trying to learn, such as a garden hose, or soil. Irrelevant information, items not related to the item(s) to be learned, form a distraction. An individual's ability to deal with distraction directly affects their ability to learn and remember pieces of relevant information (Healy, Campbell, & Hasher, 2008).

Learning Environment

Environmental or sensory enrichment, involves engaging all of the senses with relevant information. Consider the example of learning a list of flower types.

Engaging the olfactory, tactile and visual systems with relevant sensory information, the smell of a rose, the feel of thorns, the sight of bright pinks and reds, can enrich the learning environment. This enrichment has been found to improve learning and memory by strengthening the memory trace (Baroncelli, Braschi, Spolidoro, Begenisic, Sale, & Maffei, 2009). For the purpose of this thesis we are most interested in the role of motor information in the enrichment of learning and improvement of memory.

An emerging field of research, the foundation of which originated with Ebbinghaus (1964), examines the enactment effect, the role of physical and motor information in the learning of non-physical items. The enactment effect is the enhanced learning and recall of non-physical items, such as a word list, when there is a physical activity paired to each item. The idea is that by engaging the motor system the learner is strengthening memory, either through an enriched sensory experience or active recall. The enactment effect may be leveraged to improve memory and recall, or maintain it, as a possible substitute for cognitive forms of memory enhancement such as verbal learning strategies. Enactment of items to be remembered has been reported to improve memory in young, older, and memory impaired participants (Feyereisen, 2009; Karantzoulis, Rich, & Mangels, 2006; Lekeu, Van der Linden, Moonen, & Salmon, 2002;).

Practice Scheduling

The order and amount of information, as well as the experience of errors, has been investigated to understand how they could modulate the effectiveness

of learning and memory. The order effect, or serial position effect, refers to phenomena of how the position in a series affects the likelihood of recall. There are two main effects of serial position: primacy and recency. Primacy refers to better recall of the first items in a list because of increased rehearsal and greater commitment to long-term memory (Bower, 2000). Recency refers to better recall for items most recently rehearsed because they are stored in short-term memory (Bower, 2000). Random presentation of items can combat the order effect, by removing the order information linking word one and two. The amount of information that an individual can process at one time is finite, but there are varying levels of information at which an individual has optimal capacity for learning and memory. It is this optimal capacity which learning and memory studies aim to quantify.

A whole field of research has been dedicated to the spacing effect, how the blocking or separation of information can improve learning and memory. Spacing has been theorized (Ebbinghaus, 1964) and supported (Balota, Duchek, & Logan, 2007; Karpicke, & Bauernschmidt, 2011) to improve learning and memory performance compared to massed practice. Many, in an attempt to enhance the benefits of spacing, have examined the most effective form of spacing, equal interval or expanding interval. Comparable benefits have been found for both equal interval and expanded interval spacing (Balota, Duchek, Sergent-Marshall, Roediger, 2006; Hochhalter, Overmier, Gasper, Bakke, & Holub, 2005; Logan & Balota, 2008). Spacing has been found to be effective in

older, memory-impaired persons (Camp, Foss, O'Hanlon, & Stevens, 1996; Camp, Bird, & Cherry, 2000). The spacing effect has been paired with the enactment effect to investigate spared capacity in person's with memory impairment, and dementia (Bird, & Kinsella, 1996).

Error

Errors in the learning process can be both beneficial and detrimental to performance. The benefit of an error during performance is the knowledge of what does not work, or the sequence or components of a performance or answer that is incorrect. Often the greatest benefits are derived from errors when there is feedback provided to direct the learner that highlights what to improve (Eppinger, Mock, & Kray, 2009). In the absence of feedback, or explicit learning to eliminate errors, incorrect patterns of performance can be learned implicitly and slow the learning process (Baddeley, &Wilson, 1994). The individual learner's capacity to process and interpret errorful experience will determine its effect on performance.

Errorless learning has been shown to be effective in healthy populations in learning word lists and face name associations (Kessels, & de Haan, 2003; Wilson et al., 1994). Recent work has demonstrated that it may not be error alone that dictates performance, with spaced retrieval providing equal benefit to learners (Haslam, Hodder, & Yates, 2011). Errorless learning has been demonstrated to be more effective than trial and error in a number of clinical populations. One explanation for this may be that errorless learners play a more passive role in the learning process than during trial and error, and this may

result in the absorption of information in an implicit way (Poolton, Masters, & Maxwell, 2005). This bears importance for persons with short-term memory challenges and impaired explicit learning, such as persons with dementia, as implicit memory is often still intact in these conditions (Kuzis, Sabe, Tiberti, Merello, Leiguarda, & Starkstein, 1999). Errorless learning has been demonstrated to reduce errors during learning, and result in superior retention and maintained performance during imposition of secondary cognitive load (Poolton, Masters, & Maxwell, 2005). A study of cognitively impaired amputees for a limb fitting rehabilitation protocol found a beneficial effect of errorless learning, with participants recalling a greater number of steps in the protocol than those in the trial and error group (Donaghey, McMillan, & O'Neill, 2010). Participants in this study were given the Addenbrookes Cognitive Examination-Revised (ACE-R), there were no significant differences in score between groups, however, 42% of participants scored below the cutoff, exhibiting cognitive impairment (Donaghey, McMillan, & O'Neill, 2010). Another study found that errorless learning was more beneficial than errorful learning in the recall of word lists in both healthy and participants with diffuse axonal injury (Ueno et al., 2009). Cognitive function of patients in this study was evaluated using the Revised Wechsler Adult Intelligence Scale, the Trail Making Tests A and B and the Rivermead Behavioral Memory Test. The implications of these experiments suggest that by carefully selecting the content studied, learning environment,

practice scheduling and error experience, one can better enhance the learners experience and outcomes.

The experiments completed in this thesis were designed to pair the proposed benefits of motor information, through enactment, and optimized practice scheduling, spacing retrieval and errorless learning, to improve learning and memory in participants across several age groups and cognitive abilities.

Motor Information in Disease

Through the study of clinical populations, or diseased systems, we can often unearth the most interesting details of function. One classic example of the benefits of this approach was the study of Patient H.M. Through experiments conducted by Brenda Milner, and her colleagues, H.M. helped define many concepts we take for granted in memory and learning today (Milner, 2005). In an attempt to control his severe epilepsy, H.M's medial temporal lobes were resected in 1953 that resulted in complete and continuing memory loss for recent events. Findings from Magnetic Resonance Imaging of Patient H.M revealed the lesion was bilaterally symmetrical, including the medial temporal polar cortex, most of the amygdaloid complex, almost all of the entorhinal cortex, and half of the rostrocaudal extent of the intraventricular portion of the hippocampal formation (dentate gyrus, hippocampus and subicular complex) (Corkin, Amaral, Gonzalez, Johnson and Hyman, 1997).

Despite this large resection, neuropsychological testing revealed that H.M. was able to learn and retain new perceptual-motor skills such as mirror tracing

(Milner, Corkin, & Teuber, 1968). Mirror tracing is a procedural skill, thought to involve cerebellar activation (Gabrieli, Stebbins, Singh, Willingham, & Goetz, 1997). The most interesting characteristic of this learning was that H.M had no conscious memory of ever having completed the task in previous training sessions, so improved performance on the task, in light of the amnesic impairments, came as a surprise to the researchers. This work provided unique evidence that motor information may be stored and retrieved independently of other cognitive and sensory information. In the case of impaired cognition, motor information could be used to store and access information, when other verbal or explicit memory dependent pathways are less effective. This thesis is based on the claim that separable motor information pathways exist, and can be leveraged to improve performance and learning across the lifespan.

Building on this work, Dick and colleagues have completed a number of experiments examining the role of spared motor learning in persons with mild cognitive impairment (MCI) and probable Alzheimer type dementia. Cognitive dysfunction in MCI and Alzheimer Type dementia is thought to be a result of neurofibrillary accumulation that begins in the entorhinal cortex spreading to the hippocampus and other limbic structures disrupting memory (Braak & Braak, 1991). These studies have demonstrated spared capacity to learn motor tasks, as well as revealing differences in benefit by practice schedule (Dick, Hsieh, Bricker, & Dick-Muehlke, 2003; Dick, Hsieh, Dick-Muehlke, Davis, & Cotman,

2000; Dick, Nielson, Beth, Shankle, & Cotman, 1995; Dick et al., 1996; Yan & Dick, 2006).

The three experiments in this thesis were designed to follow the impact of motor information from performance to learning, characterizing the effect of this information on simple postural sway, a motor-centric communication task and learning of a novel gaming task. By beginning with performance we can examine the impact of motor information as a form of online environmental feedback. In learning we can observe and report on the storage and retrieval of motor information when paired with items to be remembered in a more complex motor communication task. Finally, we examined this information and its role in a cognitively challenged system, where motor information has the potential to compensate for decreased cognitive function. Below is an introduction to three hypotheses that comprise this thesis and the manuscripts that detail the experimental protocols used to explore these hypotheses.

Hypothesis 1

Physical information, in the form of a short duration light touch, can be used to improve balance by providing an update of the physical environment. Reginella, Redfern and Furman (1999) suggest that upper extremity touch provides sensory inputs that assist in supplying an accurate representation of spatial orientation.

Experiment 1

The first manuscript included in this thesis focused on the role of light touch in the maintenance, and recovery, of balance. Anecdotally it is has been reported that light touch, from a cane or another person, can provide stabilization when balance is disrupted. A number of studies have examined the role of sustained active and passive light touch in maintaining balance (Krishnamoorthy, Slijper, & Latash, 2002; Nagano, Shinsuke, Hay, & Fukashiro, 2006). A number of these experiments have demonstrated that light touch can maintain and improve standing balance in young and older participants (Rinaldi, Federighi, Vannucchi, Paci, & Masotti, 2007;Tremblay, Mireault, Dessureault, Manning, & Sveistrup, 2004).

The manuscript 'The Effect of Short Duration Light Touch on Balance' examined several variables of balance, visual feedback and stance difficulty, and the interaction of these components with light touch. The light touch was passive, and administered by request, when participants felt unstable, and at matched time intervals for yoked participants. This study was designed to determine if short duration light touch provided any benefit to maintenance of balance, and if this benefit was modulated by the presence/absence of visual feedback and stance difficulty. The purpose of this study was to shed light on the role of motor information in control and the circumstances under which it may be beneficial to performance.

Once we have examined the role of information in control, it is natural to move on to what this role may be in learning. Learning represents the integration

of the motor information for future use, evolving from an online control mechanism examined in the first experiment, to a consolidated form of memory available for recall. Building on previous work in the fields of enactment, we explore the role of motor information compared to visual information in learning a motor communication task. The role of motor information is examined in younger and older adults to characterize how the enactment effect might change with age.

Hypothesis 2

Physical enactment of an item to be remembered will improve memory for that item in comparison to rehearsal with visual information.

Experiment 2

The second manuscript included in this thesis examines the enactment effect and role of expanded retrieval in a task that engages both motor and cognitive domains. Younger and older participants in this experiment were separated into two groups, one group enacted hand shapes representing letters and words in American Sign Language, and one group visually studied expert performance of the same hand shapes. Participants were exposed to a set of hand shapes and asked to recall this information at increasing intervals. Once a participant had successfully recalled the information at all recall points a new set of hand shapes was presented. If the participant failed to recall at all time points the trial was started from the beginning. This format was based on errorless learning protocol, where experience of errorful performance must be limited.

Participants were required to recall both the current and preceding sets of hand shapes, when they were no longer able to do this the learning session ended. This experiment was designed to determine if there is a benefit of enactment, compared to recognition or observation, of hand shapes in American Sign Language, and what the characteristics of this benefit are with respect to randomization, immediate and long-term retention. These effects were studied in both young and older cohorts to determine if there were changes in the characteristics of this effect across the lifespan. The third experiment explores how motor information may be utilized in disease, when cognitive systems are challenged or dysfunction, such as in Alzheimer Type Dementia. Examination of the role of motor information in disease will shed light on whether or not this information is compensatory, not just additive as demonstrated in previous work.

Hypothesis 3

Persons with dementia will be able to learn and retain a new motor centric task based on evidence of spared motor learning in dementia.

Experiment 3

The third manuscript included in this thesis addresses the role of motor information in learning and control in disease, specifically Alzheimer type dementia. This case-based research design examined the spared capacity of persons with Alzheimer type dementia. The study used a physically interactive video game, Nintendo Wii TM, to probe the ability of persons with dementia to learn a motor centric task, Bowling. The variables of interest included bowling

score, knowledge of sequence of movements/controller use and ability to select the correct Mii. This study was designed to capture the interaction between motor engagement and memory in persons with dementia, with the hope of leveraging spared motor capacity to improve learning and performance.

The following three chapters contain the manuscripts outlined above. These manuscripts explore the role of motor information in behavior and learning, in the presence of physical and cognitive challenges. The first manuscript has been submitted to the Journal of *Gait and Posture*, the title of this manuscript is “The Effect of Short Duration Light Touch on Balance”. The second manuscript is being prepared for submission; the title of this manuscript is “The role of enactment in learning a motor communication task”. The third manuscript has been published in the journal, *Activities, Adaptation and Aging*, the title of this manuscript is “Exploring Spared Capacity in Persons with Dementia: What Wii TM Can Learn!”.

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Running head: SHORT DURATION LIGHT TOUCH AND BALANCE

The Effect of Short Duration Light Touch on Balance

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Abstract.

Previous research has examined the positive effect of sustained light touch on balance, specifically by decreasing sway. No study to date has examined whether short duration light touch can also have a positive effect in balance. Participants were assigned to one of two groups, self-regulated and yoked and completed one-leg and tandem stance trials in three conditions: control, breeze (environmental change to produce constant light wind sensation on skin surface), and light touch. Significant effects of stance and vision were found, as well as a trend towards greater reduction of sway with light touch that failed to reach significance. Greatest reductions occurred in more challenging stance and vision conditions, supporting a possible beneficial role for short duration light touch in absence of visual information.

Keywords: balance, sway, light touch, tandem, one-foot

Introduction.

Optimal control of balance requires the use and integration of a number of sensory inputs: visual, vestibular, and somatosensory. Light touch (LT) is one type of sensory input that can be used to improve balance. The use of LT has been shown to improve balance stability in young and older adults (Tremblay, Mireault, Dessureault, Manning, & Sveistrup, 2004; Baccini et al., 2007), in a number of stance conditions (Dickstein 2005; Clapp & Wing, 1999; Johannsen, Wing, & Hatzitaki, 2007), using a number of different 'types' of touch, such as active or passive, and with light touch applied to various locations on the body (Nagano, Shinsuke, Hay, & Fukashiro, 2006; Krishnamoorthy, Slijper, & Latash, 2002). These improvements in balance with LT have implications for rehabilitation and therapeutic use, such as the rehabilitation of gait in stroke and other disorders that may disrupt balance (Jeka, 1997).

The nature of the touch information has been examined in order to understand its role in improvements in balance. Several studies have examined the effects of the location of touch on balance, such as the finger (Baccini et al., 2007; Dickstein, 2005), leg (Nagano et al., 2006), shoulder (Johannsen et al., 2007), and head and neck (Krishnamoorthy et al., 2002). In a comparison of these locations, the greatest benefit was observed when LT was applied to the head and neck, which was attributed to the trunk-related context of the touch (Krishnamoorthy et al., 2002). Other studies have examined the delivery style of the touch, such as whether the touch is passive or active. Passive touch is the

application of a small amount of force to the body of the participant, while active touch is the application of an equal amount of force on an object by the participant. Inconsistent results have been reported related to the role of active or passive touch in improving balance. Riley, Stoffregen, Grocki and Turvey (1999) found that only those engaged in active touch (and when made aware that touching was an important task demand) demonstrated reduced sway. However, it has been postulated that this sway reduction might not be exclusively due to the active LT but rather the maintenance of steady force active touch by the participant, acting as a dual task condition (Mitra & Frazier, 2004).

Several mechanisms have been proposed to explain the beneficial effect of LT on balance. First, active light touch may provide a time-advanced cue to sway. That is to say participants may engage a light touch just prior to the body-experiencing imbalance. For example, a number of studies have found correlations between active LT contact force and foot centre of pressure (COP) with a change in contact force preceding changes in COP (Clapp & Wing, 1999; Rabin, Borotlami, DiZio, & Lackner, 1999; Jeka & Lackner, 1994). Second, LT may provide a fixed reference point in space. Reginella, Redfern and Furman (1999) suggested that upper extremity touch provides sensory inputs that assist in supplying an accurate representation of spatial orientation. Third, feedback provided by transient forces developed between the body part and the contact surface may assist in reducing sway. This mechanism proposes that slowly adapting receptors provide information related to the location of point of contact

and slow-fast adapting receptors are activated by sway-associated deformation of skin and subcutaneous tissues (Krishnamoorthy et al., 2002).

No study has examined the temporal components related to the delivery of the LT. For example, shortening the duration of LT and altering the timing of the LT (i.e., when the LT is applied during the trial) may produce different effects on balance. Thus, does the benefit to balance result from the sustained, supportive nature of the LT or could a shorter duration touch provide similar environmental cues and sensory feedback to improve balance? The primary objectives of the current study was to examine, 1) whether short duration LT will reduce sway, 2) whether there is a critical time point for the application of short duration LT to observe improvements in balance, 3) if breeze, the sensation of air movement on skin surface, provides a benefit to balance as a means of 'light touch,' 4) whether the benefits of LT are dependent on stance task difficulty, and 5) the role served by visual feedback in these effects. If short duration LT improves balance then this would support the idea that LT provides more than just physical support. This would also support the claim that intermittent feedback can provide comparable results to constant feedback (Wallis, Chatziastros, Tresilian, & Tomasevic, 2007). Moreover, this would suggest that LT provides sensory feedback of the body's location in space. This mechanism would also be supported by a demonstrated benefit of breeze as a form of LT. If the timing of the LT administration is revealed to be critical then this would support the benefit of LT as more event related then necessary for general balance.

Materials and Methods.

Participants.

Healthy young adults, twelve females and six males between the ages of 20-26 participated in this study. Exclusion criteria included any self-reported musculoskeletal, neurological, or sensory deficit that could interfere with balance. All participants were recruited from the university campus through posts in the daily news, and provided informed consent. The McMaster University Research Ethics Board approved this project.

Apparatus.

Trunk movements in the roll (i.e., side to side) and pitch (i.e., forward to backward) directions were recorded during each trial to provide an estimate of actual balance using the SwayStar System (SwayStar System, Balance Int. Innovations, GmbH, Switzerland; Allum & Carpenter, 2005). The trunk movement-recording device was attached to an elasticized motorcycle belt. The belt was fitted to the participant with the device at the level of the lower back (lumbar spines 2–3). Trunk sway angle area was used to estimate overall balance. The trunk sway angle area is the area defined by the envelope of the trunk pitch and roll angular excursions when these variables are plotted as an x–y plot. This method of recording trunk sway has been engaged in a number of experiments exploring the dynamics of postural stability and balance (Huffman, Norton, Adkin & Allum, 2010; Shaw, Huffman, Frank, Jog & Adkin, 2011).

A hand-held apparatus was used to provide the short duration LT. This device had a force transducer (FlexiForce Thin Sensors) attached to the end in order to control for force of touch (Tekscan, Boston MA). The LT was applied between the shoulder blades, with a force no greater then 3N for duration of 2 sec. The experimenter who was administering the touch reported any trial over 3N and it was removed from consideration.

Protocol.

All participants were fitted with the trunk sway measurement system. All participants were barefoot and wore light fitting clothes with bare arms and legs. Clothing was selected in order to ensure sensation of light breeze directly on the skin surface for the breeze trials. Participants were assigned to either self-regulated or yoked groups. The yoked participants were matched by gender and age. There were three conditions: control, breeze and LT. Three trials of each condition were completed with eyes open, and eyes closed, in random order. Participants were instructed to stand on one-foot or in tandem Romberg heel-to-toe position, and asked to stand as still as possible. Participants were instructed to look straight forward on eyes open trials; on eyes closed trials they were asked to direct their head forward, chin up and keep their eyes closed. Participants stood approximately four feet from the source of the breeze. The source of the breeze was an oscillating fan placed approximately four feet from the participant.

Participants in the self-regulated group were instructed to ask for a short duration LT when they felt unbalanced (by simply saying ‘touch’), instructing

participants to try and maintain optimal balance, to stand as still as possible. Yoked participants received a LT at the time intervals that had been requested by their self-regulated counterpart.

Analysis

The variable analyzed to quantify balance in this study was total angle area (TAA) of the trunk. Data was averaged across each trial in order to get a mean value for angular area of the trunk during each different stance, and then averaged by participant across trials, in order to get a mean value for each participant's performance. Conditions were then compared, control versus breeze and LT, to determine the differences in TAA resulting from the treatment, breeze or LT. In order to protect the assumption of homogeneity any trials greater then a z score of 2.65 were removed (according to Grubb's test). A total of 60 trials were removed because they were outliers, out of a total of 648 trials. A 2x3x2x2 mixed factorial ANOVA with repeated measures on the last three factors was used to examine differences between the two groups (self-regulated and yoked), three conditions (control, light touch and breeze), 2 stances (one-foot and tandem) and 2 visual conditions (eyes open and closed). This analysis addressed each of the five objectives of this project. The between-group comparison addressed the role of a timing component in the effect of light touch, repeated measures will address whether light touch and/ or breeze made an impact on sway, and what role visual condition and stance have on sway and the effect of the light touch.

Results

As expected, the ANOVA revealed main effects for vision ($F(1,16)=26.025$, $p<0.001$) and stance ($F(1,16)=28.419$, $p<0.001$), which replicates previous literature that sway increases with increasing difficulty of stance and when visual information and feedback is removed (Duarte & Zatisiorsky 2002). Mauchly's Test of Sphericity, with correction factor, revealed a significant interaction between condition, stance and vision ($F(2,15)=0.376$, $p=0.043$). A greenhouse-geiser correction factor was used and the interaction was no longer significant ($p=0.822$). Group and comparison means can be found in Table 1.

The remaining results will be presented by experimental objective. The first objective was to determine whether short duration light touch would reduce sway. Comparison between conditions (control, breeze and light touch) revealed a trend toward reduced sway during light touch but failed to reach significance ($F(2,15)=3.3$, $p=0.065$). (See figure 1)

The second objective was to investigate whether there was a critical time point for the application of light touch to observe reduction in TAA, i.e. if participants in the self regulated group would experience greater reduction of sway as a result of light touch than their yoked counterparts. Comparison of condition by group revealed no significant differences ($F(2,15)=1.303$, $p=0.301$). Light touch appeared to provide no event-related benefit in reduction of sway. The number of light touch requests per self-regulated/yoked pair for each condition were graphed to illustrate differences in individual TAA between conditions (see figure 2). These figures show that on average, the greater

number of light touch requests occurred with the greatest TAA values for self-regulated participants, while the same was not true for their yoked counterparts.

The third objective was to determine if breeze provides a benefit to balance as a means of light touch. As mentioned in the first objective, there were no significant differences between conditions. There were no reductions in sway when mean TAA was compared for control and breeze. (See figure 1)

The fourth objective was to determine whether the benefits of light touch were dependent on, or modulated by, stance difficulty. Comparison of the condition by stance interaction revealed no significant differences ($F(2,15)=0.208$, $p=0.815$). Comparison of mean TAA reveals a trend towards greater reduction of sway in light touch trials compared to control for tandem stance compared to one foot, 37.6% and 13.9% reduction, respectively.

The fifth objective was to examine the role of visual feedback in these balance conditions. There was a main effect for vision ($F(1,16)=26.025$, $p<0.001$), with eyes closed trials having significantly greater TAA values then eyes open. There was also a main effect for stance ($F(1,16)=28.419$, $p<0.001$), with one-foot stance having significantly greater TAA values then tandem. There were also two interaction effects; vision and stance, vision and group. TAA values for one-foot eyes closed were significantly higher than tandem stance eyes closed ($F(1,16)=24.699$, $p<0.001$). TAA values for the self-regulated group were significantly higher for eyes closed trials then the yoked group ($F(1,16)=5.414$, $p=0.033$). Mauchly's Test of Sphericity, with correction factor,

revealed a significant interaction between condition, stance and vision (F (2,15)=0.376, p=0.043). A greenhouse-geiser correction factor was used and the interaction was no longer significant (p=0.822). Examination of means illustrates a trend toward increased benefit of light touch in eyes closed, versus eyes open conditions. This trend suggests that in the absence of visual information, motor information may play a compensatory role in providing information about the environment that may decrease sway (see figure 3). A post hoc power calculation was done to help determine the accuracy of statistical outcomes for comparisons in the light touch study. Comparisons had an average Cohen's d of 1.79, with a range of 0.55-3.12, resulting in a power less than or equal to 0.25.

Discussion

The primary objectives of this study were to determine 1) whether a short duration LT would reduce sway, 2) if there was a critical time point for this touch to be effective, 3) to determine if breeze, the sensation of air movement on skin surface, provided a benefit to balance as a means of 'light touch', 4) whether the benefits were dependent on stance task difficulty, and 5) the role of visual feedback in these balance conditions.

Each objective will be addressed below with suggestions as to which existing theory these results support.

Can short duration LT reduce trunk sway?

Although the differences did not reach significance, figure 1 illustrates a trend towards light touch trials (M=21.7) having less sway (i.e., a lower TAA value), than control (M= 24.9) or breeze (M= 27.4) conditions. These findings suggest that more research on the potential beneficial effect of light touch on sway is warranted.

Is there a critical time point for this touch to be effective?

There was no significant difference between the self regulated and yoked groups for light touch. This finding suggests that the benefit of light touch was not event related in this case, which supports the idea that light touch benefits sway by providing an update of the body's position in space. This update is a general piece of information, which provided equal benefit when either specifically requested or randomly received.

Does a light breeze simulate a LT?

There were no significant effects observed for condition, and further examination of trends for breeze versus control and light touch trials shows that breeze may have actually increased sway in the self-regulated group (figure 1). Based on these trends we conclude that breeze does not provide a benefit similar to light touch for the reduction of sway.

What role does visual feedback play?

Lack of visual information (eyes closed trials), demonstrated an increase in sway for both stances. This finding implies that the presence of visual information reduces sway. The visual system, similar to what has been hypothesized about

the motor system engaged by light touch, appears to provide environmental information which aides the maintenance of balance by providing the body with a fixed reference point in space (Reginella, Redfern & Furman, 1999).

Limitations

The large amount of variability found both within and between groups in this experiment must be addressed as a limitation. There are several explanations for this variability, including previous experiences and perception of light touch. Previous experience in sport or activities that train balance could create significant differences in sway between subjects. Perception of light touch may vary between subjects, with some perceiving it as helpful, while others may perceive it as a perturbation.

General Conclusion

In conclusion these data demonstrate that:

(1) Short duration LT may be beneficial in reduction of sway. However, this benefit was only seen in the absence of visual information. This finding implies that motor information is a secondary system that may be engaged in the presence of increased challenge, such as increased difficulty of stance and absence of visual feedback.

(2) Breeze does not appear to provide a beneficial source of light touch. The breeze condition, designed to be a ‘lighter’ light touch, did not provide any

significant reduction of sway. This suggests that actual skin-to-skin, or skin to object, contact is required to qualify as a light touch.

Future research should explore how short duration light touch can be analyzed on a more event-related basis, to determine how the light touch can impact sway, and if this effect is dependent on individual perceptions of sway, force used, or nature of stance condition.

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Figure Captions

Figure 1. Mean Total Angle Area (TAA) by condition reveals a trend towards reduction of sway with light touch.

Figure 2. Number of light touch request per pair of participants (SR/Yoked) presented by condition: (a) One-Foot Eyes Open, (b) One-Foot Eyes Closed, (c) Tandem Eyes Open, (d) Tandem Eyes Closed

Figure 3. Light touch trials compared to control for vision and no vision trials.

Table 1. Group and comparison means and standard deviations.

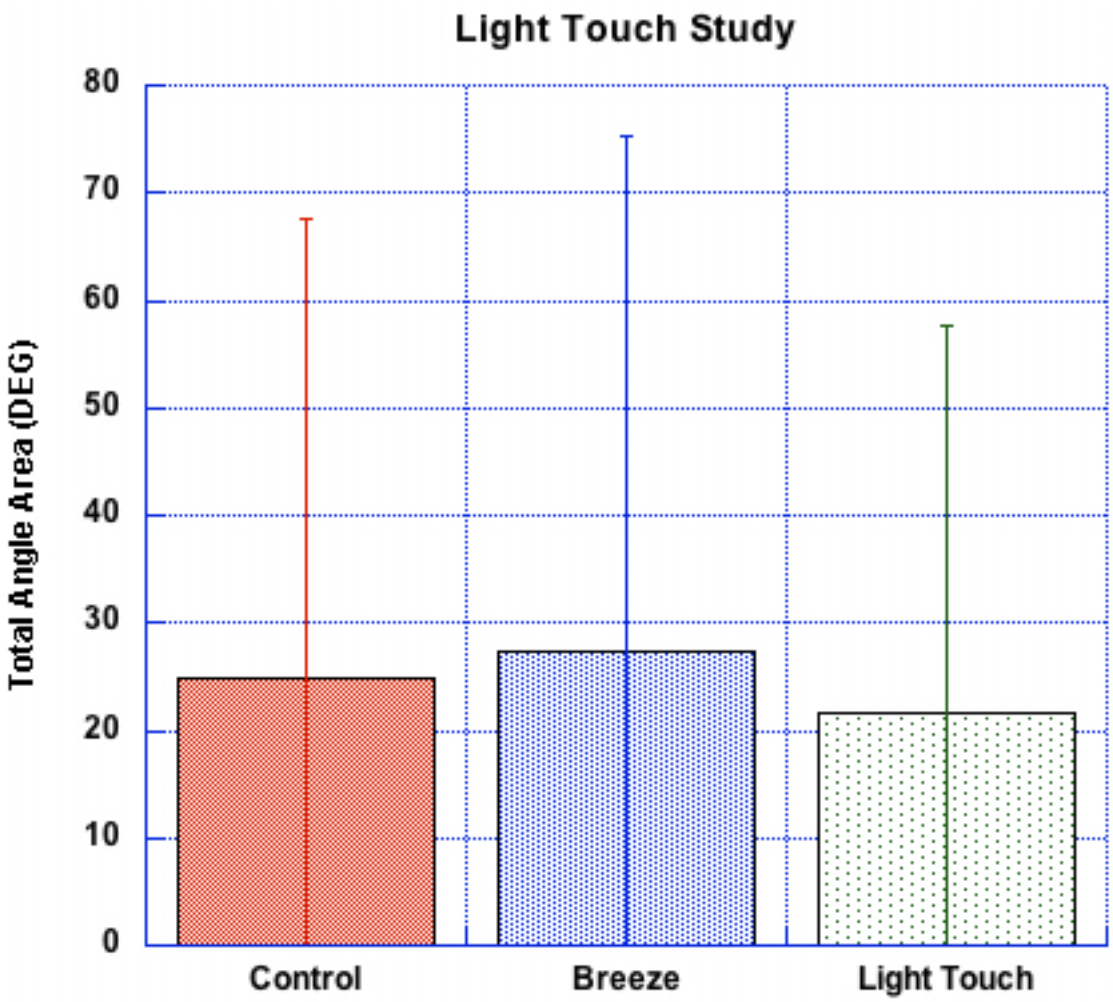

Figure 1. Perturbation main effect. Perturbation main effect (F (2,15) = 3.3, p = 0.065) was not significant.

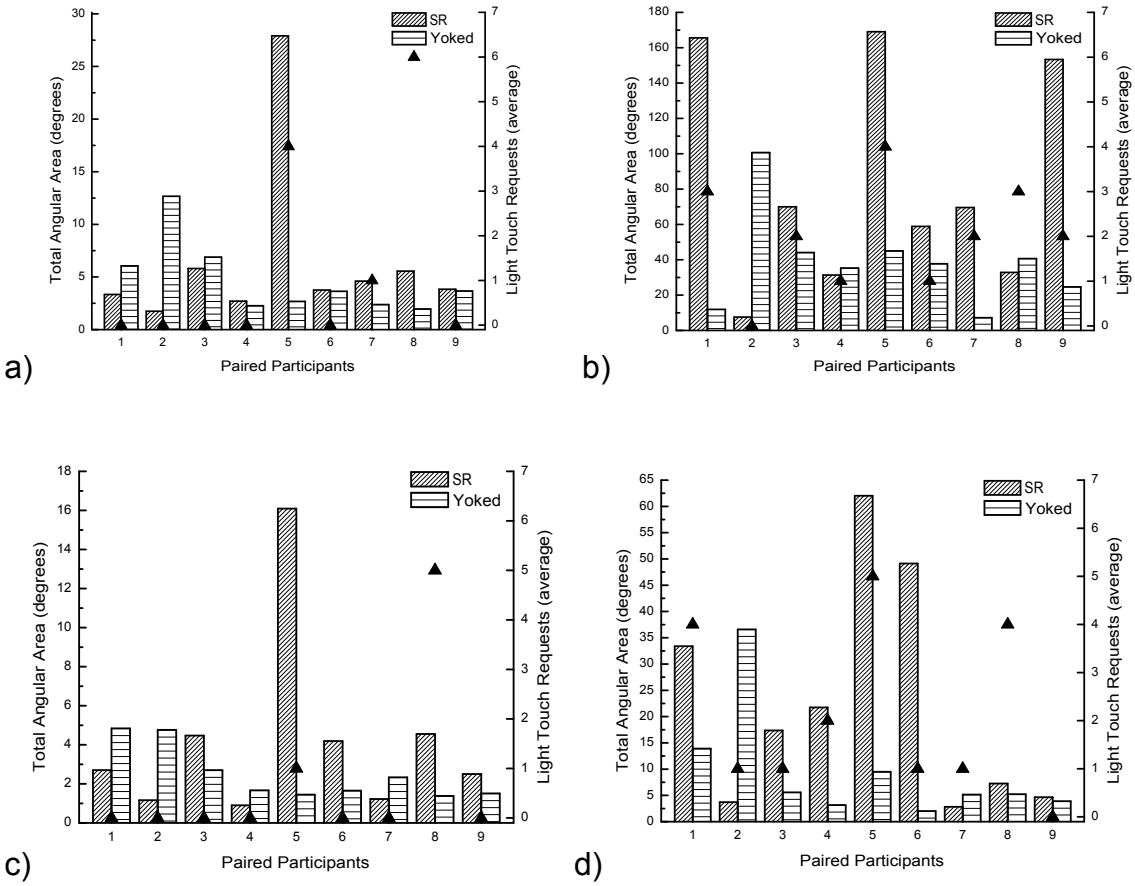

Figure 2. Number of light touch request per pair of participants (SR/Yoked) presented by condition: (a) One-Foot Eyes Open, (b) One-Foot Eyes Closed, (c) Tandem Eyes Open, (d) Tandem Eyes Closed

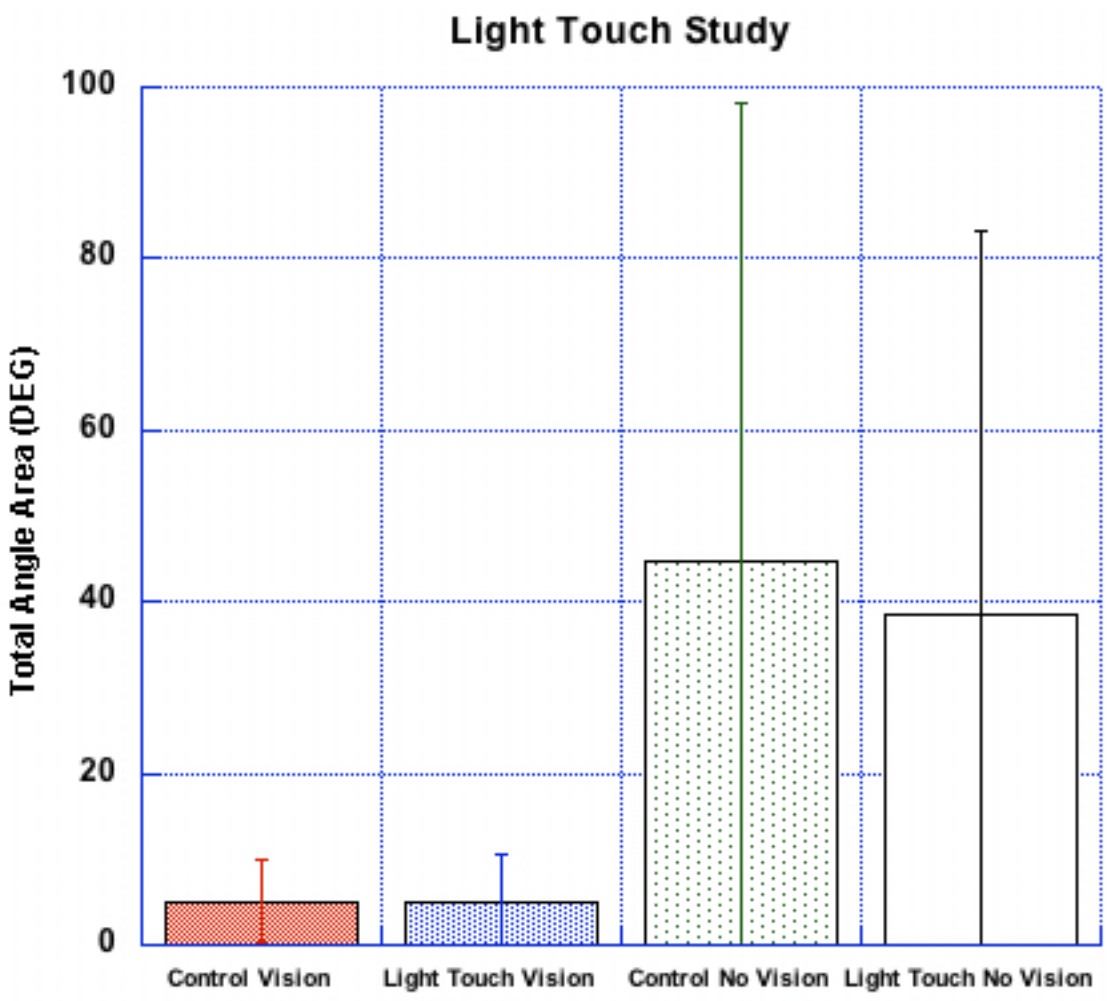

Figure 3. TAA for control and light touch trials with and without vision.

Table 1. Group and Comparison Means and Standard Deviations

	Total		**SR**		**Yoked**	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Control 1ft EO	6.12	4.98	6.06	4.49	6.18	5.71
Control 1ft EC	73.47	66.71	100.35	77.90	46.59	41.97
Control Tandem EO	4.46	4.80	5.28	6.52	3.64	2.20
Control Tandem EC	26.53	39.12	41.86	51.13	11.21	10.45
LT 1ft EO	6.49	6.93	8.35	9.07	4.63	3.48
LT 1ft EC	61.41	52.12	84.24	62.21	38.58	27.00
LT Tandem EO	3.24	3.43	4.16	4.70	2.32	1.00
LT Tandem EC	16.58	17.51	22.46	21.53	10.70	10.48
Breeze 1ft EO	6.61	4.38	6.75	4.44	6.48	4.57
Breeze 1ft EC	74.95	69.03	106.70	86.16	43.20	20.85
Breeze Tandem EO	3.69	4.45	4.73	6.13	2.65	1.44
Breeze Tandem EC	24.18	37.11	38.67	49.38	9.69	3.90

Running head: ENACTMENT AND MOTOR LEARNING

The Role of Enactment in Learning a Motor Communication Task

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Introduction

A growing volume of research is dedicated to understanding the role of physical engagement in learning, memory and retrieval; however, this is by no means a new field of inquiry. Herman Ebbinghaus (1964), a pioneer in the study of learning and memory, proposed a model that plotted the rate of forgetting and the factors that influenced the process of forgetting. Memory strength was dependent on two factors in his model: memory representation and active recall. Memory representation can be improved through environmental enrichment, which involved adding to the memory representation sight, sound, scent and tactile input to enhance memory for an item. Active recall, or spaced repetition, improves memory strength through repetition of the item to be remembered, by increasing time between recall the memory trace is being strengthened (Karpicke & Blunt, 2011; Kornell, Eich, Castel, & Borch, 2011).

Environmental enrichment, the first component of Ebbinghaus's memory strength model, can include visual, auditory, olfactory and tactile stimulation to engage multi-modal processing. Enactment engages tactile sensation by pairing a physical activity or movement to an item to be remembered. Research has consistently shown that enactment of verbal items provides enhanced memory performance compared to traditional verbal recall tasks (von Essen, & Nilsson, 2003). An example of enactment of verbal items would be bringing your hand to your mouth to mime eating, when spoon or fork is the verbal item to be remembered. There are four main theories in the literature proposed to explain

the enactment effect [also referred to as participant performed task (SPT) effect]. The first theory, proposed by Cohen (1983), suggests that the enactment effect is automatic and non-strategic. Evidence exists that traditional strategic learning effects, found in verbal recall tasks, are not found when examining enactment (Nilsson, 2000). The second theory (Bäckman, & Nilsson, 1984, 1985), suggests that the enactment effect is partially automatic and derives its benefit from the multi-modal engagement that occurs during enactment, including visual, auditory and tactile stimulation (Nilsson, 2000). The third theory, proposes that enactment encoding is organized into independent visual, auditory and motor programs, with the motoric being the most efficient, evidenced by the enactment effect (Engelkamp, & Zimmer, 1983, 1984, 1985). The fourth theory contradicts the non-strategic proposal of Cohen by suggesting that the enactment effect is entirely due to self-involvement and experiential registration, or episodic encoding of a personal experience (Kormi-Nouri, 1995).

The Cohen and Backman/Nilsson theories have converged in light of recent data. The current belief of both groups is that the non-strategic nature of enactment is maintained with the specification of physical movement and multi-modality encoding as critical components (Nilsson, 2000). Several experiments have shown that enactment, although the interpretation of the cause of this improvement remains controversial (Feyereisen, 2009).

The second component of Ebbinghaus' model of memory is active recall. Active recall can improve memory strength through spacing, repetition, and

timing. Manipulating the interval between study and recall can strengthen the memory trace. The spacing effect has been found across tasks and age, spacing information improves retention, compared to massed presentation, specifically in the long term (Balota, Duchek, & Logan 2007). The most effective form of spacing has been debated, with evidence supporting benefits of both equal and expanded spacing, with no robust differences between the two (Balota et al., 2006, Logan, & Balota 2008). Equal spacing refers to intervals of equal length (e.g. every interval is one minute), while expanded spacing involves increasing time intervals (e.g., the first interval is 30 sec, the next 1 minute, the next 2 minutes, and so on). Interestingly, expanded retrieval has proven uniquely effective in young (Rea, & Modigliani, 1987) and older adults with memory impairment (Camp, Foss, O'Hanlon, & Stevens, 1996; Camp, Bird, & Cherry, 2000). A more recent study by Hochhalter, Overmier, Gasper, Bakke, and Holub (2005), involving persons with dementia, found comparable benefit for equal and expanded interval retrieval. It appears, regardless of the type of spacing, that there is a benefit to spacing of information and recall for learners across the lifespan.

Not only is the spacing of information and retrieval important, but so too is the type of experience and feedback during performance. The feedback of interest in this work is the acknowledgement of correct or incorrect performance, referred to as trial and error (or errorless) learning. Trial and error involves learning through just that, trials and errors, using error information to improve

performance (e.g., if that did not work maybe this will). Errorless learning requires the participant to have limited experience with error. This is achieved by observation of the correct performance and practice of that performance. Although in many cases trial and error may provide unique information by which to learn, this error must be minimized in some sense to limit the possible solutions to a proposed action (Fetters, 2010). Errorless learning was selected for this experiment so that it could be replicated in the future with clinical populations for comparison of this motor communication task across the lifespan. Errorless learning is thought to be beneficial for rehabilitation in persons with memory disorders as it reduces load on working memory (Baddeley, & Wilson, 1994). Specifically, errorless learning has been found to enhance learning and memory, compared to errorful learning, in amnesiacs (Baddeley, & Wilson, 1994)

The combined effect of enactment, expanded retrieval, and errorless learning for a motor communication task is not well understood. There is also a lack of evidence to accurately characterize the modulation of these effects across the lifespan. Evidence for improved roll of enactment and spaced retrieval in older, cognitively impaired persons suggests that motor benefits may increase with greater cognitive challenge. This has implications for cognitive challenge and natural memory loss with aging.

The following studies were designed to leverage the benefits of environmental enrichment and active recall to improve memory. In the present study we examined the enactment effect, compared to recognition learning, using

an expanded retrieval, errorless protocol in young (experiment 1) and older persons (experiment 2).

EXPERIMENT 1

The task selected for this experiment was learning of hand shapes for letters and words in American Sign Language (ASL). Sign language is a motor communication task that, for the learner, pairs the English word with the sign language hand-shape. This task was selected because it provided an opportunity for new learning (forming hand shapes) while contextually familiar (use of English letters, words) and involved physical engagement. Expanded retrieval was used for recall of signs to test this schedule's intrinsic ability to improve memory, and examine the combination of enactment and expanded retrieval. An errorless learning protocol was selected to examine the characteristics of learning this motor task in absence of error experience.

We hypothesized that enactment would improve learning, memory and retention of learned items, and garner better overall performance in comparison to merely learning to recognize items. Based on evidence that enactment can strengthen memory for items to be remembered.

Participants

All participants were recruited from McMaster University's graduate and undergraduate population. All participants provided informed consent, approved by the McMaster University Human Research Ethics Board. Twenty participants

aged 18-30 were included, eight males and twelve females. Exclusion criteria involved any prior experience with sign language, collected via self-report.

Method

Participants were assigned to one of two groups: enactment or recognition. Each group viewed an expert performing a sequence of hand shapes and were asked to review this video with the aim of (a) recognizing the sign in a future viewing (recognition group) or (b) enacting the sign in a future cued scenario (enactment group). Hand shapes represented letters and words in ASL, and were presented in groups of 3-6. Hand shapes increased in difficulty and number per set as the experiment advanced in order to maintain an increasing level of challenge for participants.

The recognition group was encouraged to watch the video multiple times to gain familiarity with the signs, the name of each sign was written in English at the top of the video. Participants were instructed not to attempt to form the signs with their hands. During recall participants in this group viewed the same video of expert performance without the names of each sign written on the slide.

The enactment group was encouraged to create hand shapes along with the expert viewed on the video at the beginning of each set. The video showed a close up view of the expert, torso and face, completing hand-shapes in ASL. After each recall interval participants were presented with the letters or words in English and asked to form the ASL hand shape for those items. All trials were filmed to ensure proper formation of hand shapes.

Time intervals between recall were expanding, 10s, 20s….160s. During intervals participants were engaged in one of three computer games: blackjack, hi-lo, or a shell game. The interference in the computer game was non-motor; participants instructed the experimenter on which moves, selections they wanted to make.

If the participant had successfully recalled items from the first to the last time point they moved on to the next set of signs. If an error was made they returned to the instructional slide and began the interval sequence again. Once the second set of signs was completed participants were asked to recall the signs from the previous set. If they were unable to recall the signs in the previous set the experiment ended. The experiment was halted at this point on the assumption that if the participant was unable to remember the previous set of signs, that they had reached their short-term memory capacity, and could retain no new information without replacing the older information.

Participants were asked to perform an immediate recall test of all signs they had practiced (in the same order) and a random recall test (items were presented in a random order), if participants failed to recall a sign in sequence the test was discontinued. This discontinuation of the recall test happened in all subjects who had a score lower than 32 at recall. Participant's returned six weeks later for a retention test. Participants were required to recognize signs from the expert video, as well as enact signs when prompted with the English word. All

participants performed both forms of recall; therefore each group had one familiar recall and one unfamiliar (based on their original learning condition).

Dependent Measures

Number of items recalled was compared within group across retention sessions as well as between groups. There were three data points, immediate recall, random recall and six-week retention. Immediate recall was the number of items recalled by participants during the learning session. Random recall was the recall for items out of their original order during learning. The final retention test occurred six-weeks after the initial learning session. Participants were required to recall items by recognizing them in the expert video, or performing hand-shapes when prompted by the English word. A total of thirty-two letters and words were presented to participants in this experiment. At the final retention test participants were asked to recall half the items via recognition of expert performance, and the other half through enactment of signs when an English word was presented. This created a familiar recall (recall in the method engaged during learning) and an unfamiliar recall (recall in a different method then engaged during learning).

Rate of forgetting was calculated by subtracting retention from immediate recall, dividing by immediate recall and multiplying by 100 to calculate a percentage. Rate of forgetting represented the proportion of signs learned that were recalled at the retention period. This measure allows for comparison between participants and groups with variable number of items recalled. Rate of

forgetting represents the strength of memory for items, which may help differentiate between the success of encoding via enactment or recognition.

Results

A 2-factor between/within ANOVA was used to analyze number of items recalled between and within groups. There were no significant differences between the recognition and enactment groups. Comparison of condition, in immediate recall and retention, revealed a significant difference (F (1,36)= 254.18, $p<0.01$) with the retention test eliciting a significantly lower number of items recalled. Rate of forgetting was compared between groups using a one-tailed t-test to determine if enactment had a greater or lesser rate of forgetting compared to recognition; differences reached significance (t (18)=1.848, $p<0.05$). The recognition group had a significantly greater rate of forgetting then the enactment group (see figure 1). Refer to Table 1 for group means and standard deviations. There was no significant difference in items recalled in the familiar condition between the enactment (M=5.8) and recognition groups (M=5.18), (t=0.56, p=0.577). This finding suggests that encoding through enactment or recognition provided equivalent benefit at recall when the items were recalled in a familiar method (enactment of signs for the enactment group, and recognition of signs for the recognition group).

There was a significant difference in items recalled in the unfamiliar condition between enactment (M=6.55) and recognition groups (M=2.91), (t= 2.65, p=0.0164). This finding suggests that encoding through enactment provided

a greater benefit at recall for items in an unfamiliar context, compared to recognition. The enactment group was better at recognizing signs performed by an expert, compared to the recognition group's ability to enact signs at recall.

Discussion

These results suggest that for younger people there is no specific benefit of enactment in learning, compared to recognition for the number of items recalled. The ceiling effect has been found in younger adults in enactment encoding conditions (Lovden, Ronnlung, & Nilsson, 2010), but this has not been in direct comparison to recognition. This lack of difference may be a result of insufficient challenge at the initial learning stage, or redundancy of sensory information from visual observation and physical engagement. The significant difference in rate of forgetting suggests that benefits of enactment may exist in the strength of the memory for items learned. Participants in the enactment group recalled a greater proportion of signs at the 6-week retention test, demonstrating a better memory for items then those in the recognition group. The lack of enactment effect in number of items recalled in the young group may be a result of several factors: a ceiling effect, errorless protocol at recall or nature of the task. There was a ceiling effect during learning, with most participants recalling all items at learning (a total of 32). Another possible explanation may be the errorless format of the recall sessions. The random recall session was ended immediately if a participant was unable to recall a sign, but this limited our ability

to capture any signs later in the order of recall. Both groups experienced a significant decrease in number of items recalled at retention demonstrating significant rates of forgetting. This could be a result of poor encoding at learning and initial recall, or due to the length of the retention period, six weeks. The nature of the task, motor communication, may have been very intuitive to participants, and not provided the level of challenge required to engage the enactment effect. Comparison of familiar versus unfamiliar retention scores revealed that the enactment group demonstrated significantly better retention scores in the unfamiliar retention test. This finding is in contradiction to the theory of encoding specificity (Tulving & Thomson, 1973), and suggests an improved strength of memory with enactment encoding.

Limitations

An errorless protocol was extended into the random recall portion of the experiment. This may have artificially reduced the number of items recalled by a participant. If a participant had difficulty remembering a particular sign they were prevented from recalling any other signs that fell later in the recall order. This was addressed in changes to the protocol in the second experiment. The length of the retention period may have contributed to lack of effect; therefore, it was adjusted to improve capture a more accurate picture of recall in the older cohort.

EXPERIMENT 2

Taking into considerations the limitations of experiment 1, changes were made to the protocol prior to testing the older cohort. In experiment 2 the

hypothesis remained the same, that enactment would improve learning, memory and retention of learned items, and garner better overall performance in comparison to merely learning to recognize items. If errorless learning can be beneficial when explicit learning, or working memory is challenged (Baddeley, & Wilson, 1994; Park, & Reuter-Lorenze, 2009), then enactment paired with errorless learning should help improve performance in older adults compared to recognition.

Participants

All participants were recruited using McMaster University Daily News advertisements and posters on main campus. All participants provided informed consent. Fifteen participants aged 54-77, ten females and five males, were tested. Groups were pseudo-balanced with the goal of equating for gender and age. Exclusion criteria involved any prior experience with sign language, collected via self-report.

Method

All participants were briefed about the format of the experiment prior to beginning. The experimenter administered the Mini Mental State Exam to each participant, and the data were used for within-cohort comparison only. Participants were assigned to one of two groups: recognition or enactment. The protocol of this experiment was identical to that of experiment one up to the random recall component. For this experiment, during the random recall test, participants were able to ‘skip’ a sign they could not recall and continue the test.

The spacing and number of retention tests were also adjusted for this experiment. Participants returned one week and two weeks after the initial session for retention testing. At the final retention test participants were asked to recall half the items via recognition of expert performance, and the other half through enactment of signs when the English word was presented. This created a familiar recall (recall in the method engaged during learning) and an unfamiliar recall (recall in a different method then engaged during learning).

Two measures were used to ensure homogeneity of groups in the older cohort: a mini mental state exam (MMSE) and a tactile discrimination task. The MMSE was included to ensure that participants did not suffer from any significant memory impairment prior to participation. The purpose of the tactile discrimination task was to capture the motor ability to discriminate between nonsense shapes and familiar letter shapes. This was included to parse out the ability to link motor information to meaning, letters or language, or to nonsense shapes, or physical information lacking a specific context.

The participants were asked to complete a letter and nonsense shape tactile discrimination task (Witelson, 1974). Participants were blindfolded and asked to 'feel' a shape with the right hand. The blindfold was removed and the participant was asked to select the shape they had felt from a screen containing 6 letters and/or shapes. The test was repeated with the left hand. There were a total of 8 shapes and letters.

Results

The mean age of participants participating in this study was 67.93 years old, with a standard deviation of 7.56 years. A t-test was used to compare MMSE and tactile discrimination task scores between groups. There were no significant differences for MMSE score (M= 28.69, SD=1.4, t (12)=-1.072, $p<0.05$). There were no significant differences in tactile discrimination in the left hand (M=6.78, SD= 1, t (11)=-0.746, $p<0.05$); however, differences reached significance in the right hand (M=6.08, SD=1.5, t (11)=3.187, $p>0.05$). The enactment group (M=7) made a greater mean number of correct discriminations compared to the recognition group (M=5).

A 2-factor ANOVA was used to analyze within and between group differences. There were no significant differences between the recognition and enactment groups (F (1,26)=0.265, $p>0.05$). There was a main effect of condition, immediate recall and retention, (F (1,26)= 4.611, $p<0.05$). Rate of forgetting was 23% and 51% for the enactment and recognition groups, respectively. The difference between rates of forgetting was significant (t (13)=2.128, $p<0.05$), with the recognition group having a higher rate of forgetting when compared to the enactment group (see figure 2). Refer to Table 1 for group means and standard deviations. There was no significant difference in items recalled in the familiar condition between the enactment (M=4.25) and recognition groups (M=3.57), (t=0.72, p=0.49) or the unfamiliar condition, enactment (M=4.75) and recognition (M=2.43), (t=1.47, p=0.17). This finding suggests that encoding through enactment or recognition provided equivalent

benefit at recall when the items were recalled in a familiar method (enactment of signs for the enactment group, and recognition of signs for the recognition group).

Discussion

MMSE data revealed no significant differences in cognitive ability between groups for the older adults. Analysis of tactile discrimination task results revealed that all participants had the motor capacity to learn to discriminate between language associated and non-sense shapes. There was a significant difference in the number of correct discriminations in the right hand between groups, with the enactment group having a greater number of correct discriminations in the right hand compared to the recognition group. This may be explained by differences in handedness, the fact that the discrimination task was completed on the final retention test (after three sessions of practicing hand-shapes) or 'warm up' decrement if the right hand was tested first.

Although there was a trend towards enactment improving performance at retention in the older group it failed to reach significance for overall number of items recalled. Differences in condition illustrate the significant number of items forgotten between recall sessions. Rate of forgetting was significantly different between groups, with the recognition group having a greater rate of forgetting, remembering a lower proportion of signs at retention compared to the enactment group. Individuals in the recognition group recalled more items during training

and at immediate recall, but had a greater rate of forgetting. Individuals in the enactment group did not learn or recall as many items at training and immediate recall but retained a greater proportion of what they did learn at retention. This suggests that the benefit of enactment is not in volume of items learned but the strength of memory for those items. The strength of memory, in the case of older adults, improved overall number of items recalled but did not significantly impact performance in familiar or unfamiliar recall.

Experiment 1 & 2 Results

In order to understand how the effect of enactment may be modulated by age a comparison was completed between experiment one and two. The difference between younger and older cohorts was the difference in retention period (6-8 weeks for the younger adults, and 3 weeks for the older adults), and the use of errorless learning at randomized recall (used for the first half of younger adults but removed for the second half of younger adults, and the older adults). The randomized recall score was not used for comparison within or between groups or cohorts. If the reduction in retention period was going to influence the comparison, we would assume that overall number of items recalled would be higher for the older adults (with shorter retention period) than young adults, but this was not found. This suggests that comparison between the two experiments is acceptable, even given the differences in retention period. Despite these differences a three-factor ANOVA was used to compare the results of the first and second experiments. There was a significant effect of age for

number of items recalled (F (1,62)=57.02, $p<0.05$), condition (F (1,62)=94.29, $p<0.05$), and a significant interaction between age and condition (F (1,62)=30.79,$p<0.05$). Holm-Sidak post hoc analysis of this interaction, revealed a significant difference for age within enactment, with older performing better relative to young (t=6.519, $p<0.05$), and age within recognition, with younger performing better then older adults (t=7.198, $p<0.05$). (see figure 3)

A post hoc power calculation was done to help determine the accuracy of statistical outcomes for the comparison of enactment and recognition groups for younger (d=0.9) and older adults (d=0.64). The Cohen's d value for both the young and older adults suggests that the statistical result carries practical significance (i.e. no type II error was made Wolf, 1986).

General Discussion

There are several limitations to analysis between these two experiments, namely the ceiling effect of performance in young at initial learning and the alterations in the retention protocol for the older adults. Keeping in mind these challenges we compared the two groups in an attempt to characterize the differences in the way each age group utilized motor information in the form of enactment. Both young and older adults experienced a reduced rate of forgetting with enactment, improving strength of memory for items compared to the recognition group. There were significant differences in initial learning, clearly identifying a capacity difference in young versus older adults. The apparent

increased benefit from enactment for number of items recalled with age may be related to cognitive ability or differences in memory capacity that can be challenged with age. It has been suggested that multi-sensory input can be highly redundant (Jeka, Oie, & Kiemel, 2000). Therefore, when all systems are supposedly operating at their best, such as in young cognitively healthy adults, there is no added benefit from motor information. For the older learners, all systems may be challenged, with cognitive or short-term memory impairment; this may be offset by integration of motor information to strengthen memory. This interaction suggests that motor information may provide compensatory information to bolster memory systems challenged by age related declines in performance.

Conclusion

Results from these experiments show an apparent age effect of enactment, with young experiencing no added benefit of enactment across learning or retention, and older participants nearing a significant improvement with enactment. This suggests a benefit of the use of motor information encoding during enactment in the presence of cognitive or short-term memory challenge. Further research should focus on examining this effect in persons with memory impairment, specifically dementia. Utilizing this protocol with persons with dementia will add to the enactment literature in this population, and may reveal a valid therapeutic tool for communication later in the disease. Using a motor communication task may increase the quality and quantity of communication for

persons with word-finding and verbal memory impairments, improving quality of life.

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Figure/Table Captions:

Figure 1. Rate of forgetting in young adults, enactment group versus recognition group.

Figure 2. Rate of forgetting in older adults, enactment group versus recognition group.

Fugure 3. Rate of forgetting for both younger and older adults.

Table 1. Group Means. Group means for both older and younger participants, for recall comparisons.

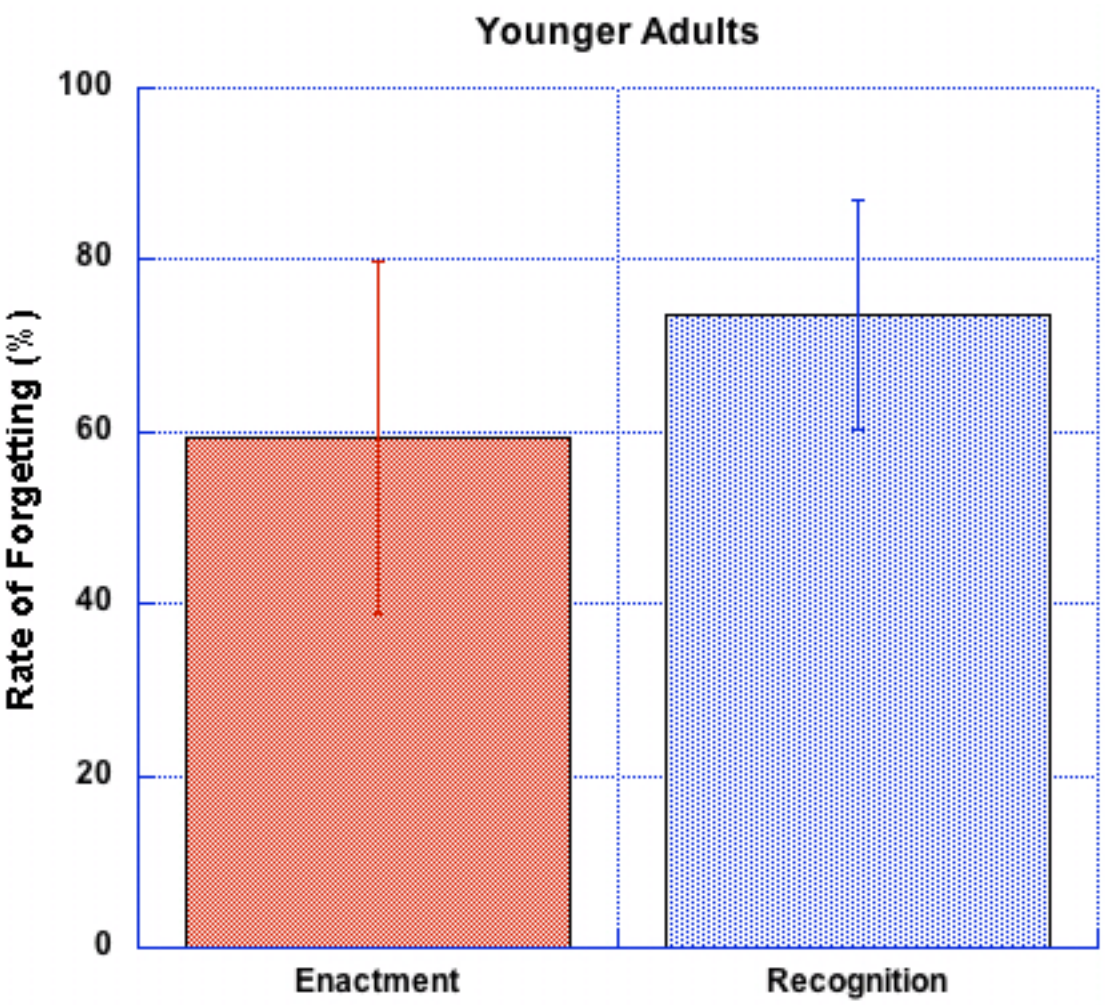

Figure 1. Rate of forgetting in young adults, enactment group versus recognition group.

Figure 2. Rate of forgetting in older adults, enactment group versus recognition group.

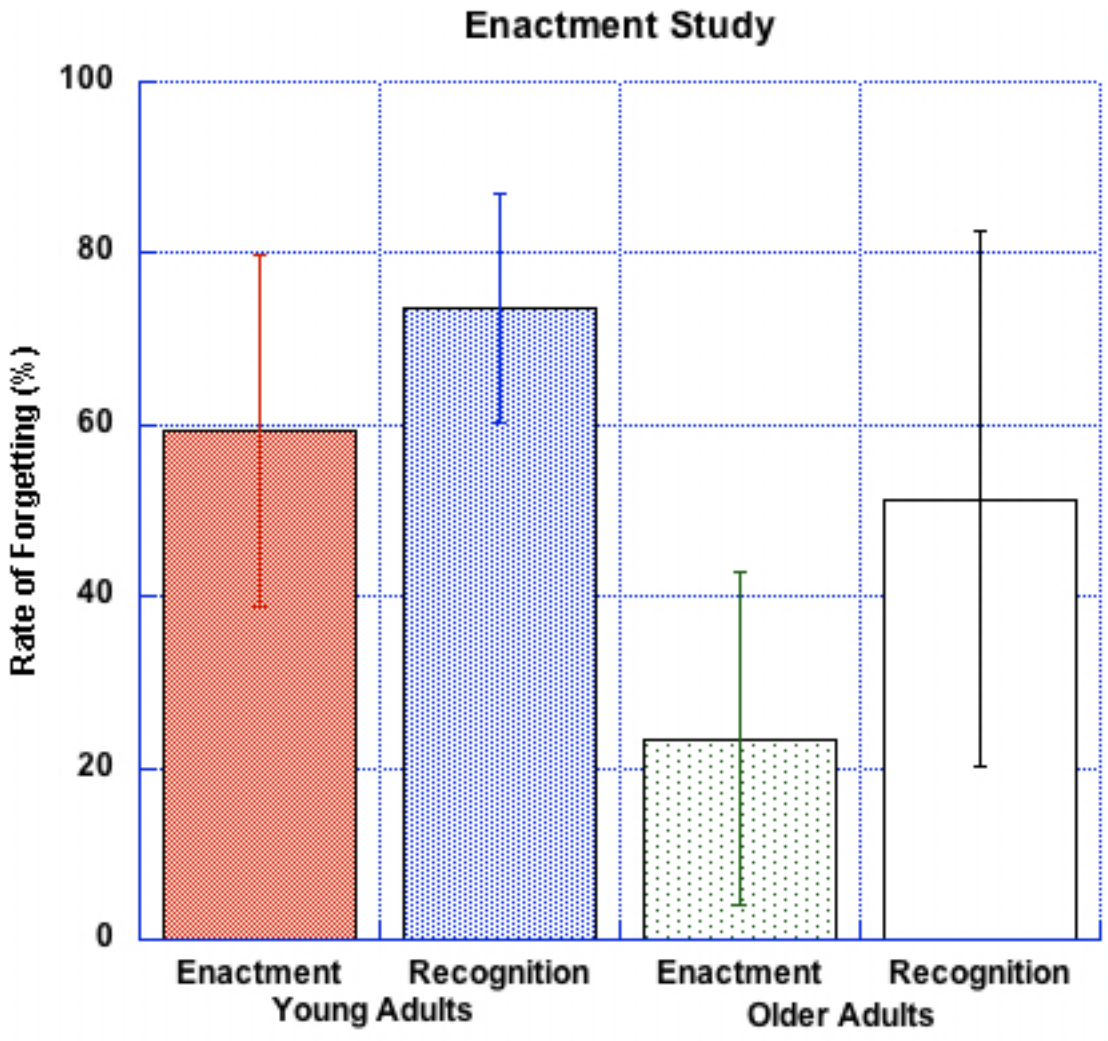

Figure 3. Rate of forgetting for both younger and older adults.

Table 1. Group Means

Enactment	Young		Older	
	Mean	***SD***	***Mean***	***SD***
Recall	31.11	1.83	10.88	10.37
Random	22.11	10.04	11.50	10.85
Retention 1 wk.	-	-	8.75	6.88
Retention 3 wks.	-	-	8.50	5.66
Retention 6 wks.	12.44	5.90	-	-
rate of forgetting	59.00	20.62	2.38	5.58

Recognition	Young		Older	
	Mean	***SD***	***Mean***	***SD***
Recall	30.55	3.21	15.57	6.24
Random	19.09	14.65	13.43	7.14
Retention 1 wk.	-	-	8.57	5.47
Retention 3 wks.	-	-	6.71	3.90
Retention 6 wks.	8.09	4.30	-	-
Rate of forgetting	73.48	13.42	8.86	7.58

Exploring Spared Capacity in Persons With Dementia: What Wii™ Can Learn

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Abstract

This study was designed to probe the capacity of persons with dementia to learn motor tasks. The activity selected was the Nintendo Wii™ bowling game. The experimenters followed three case studies throughout a 9-week training session, with a 5-6 month follow-up retention test. The participants had a dementia diagnosis, with disease duration ranging from 2 to 5 years. All participants demonstrated improvement in bowling scores and memory for procedural components of game participation that persisted up to 6 months. These results support spared motor learning capacity in dementia, supporting a need for further investigation of activity enhanced therapy.

Keywords: motor learning; dementia; interactive gaming

Introduction

Mounting evidence suggests that neural pathways used to store, consolidate, and retrieve motor memories are distinct from the pathways used for other memories. Early evidence for this distinction is found in the examination of patient H.M., by Milner, Corkin, and Teuber (1968). This patient, whose medial temporal lobes had been resected in an attempt to control severe medial temporal lobe epilepsy, was unable to retain memories for recent events. Surprisingly, however, H.M. was able to improve his performance and retain motor memories of laboratory perceptual-motor tasks, such as mirror tracing. Further evidence was provided by Dick and colleagues (Dick, Hsieh, Bricker, & Dick-Muehlke, 2003; Dick, Hsieh, Dick-Muehlke, Davis, & Cotman, 2000; Dick, Nielson, Beth, Shankle, & Cotman, 1995; Dick et al., 1996; Yan & Dick, 2006), who found dissociations when examining the effect of practice schedules on learning and retention in individuals with probable Alzheimer's disease and mild cognitive impairment. The tasks used ranged from beanbag tossing to more continuous motor activities such as rotary pursuit tracking. Although learning occurred in all these tasks, constant practice provided the greatest benefit for those with memory impairment in individuals with dementia (with variable practice negating all learning), the opposite effect to what is typically found in cognitively healthy individuals (Lee & Schmidt, 2008). Together with the evidence from H.M., these findings suggest that brain regions responsible for the acquisition and retention of motor skills may be spared the effects of induced and

naturally occurring damage.

Another area of research, involving the effects of enactment and participant-performed tasks, also reveals better-than-expected retention benefits when performed by persons with cognitive impairments. Several protocols have been designed to examine the effect of physical engagement in a task or item to be remembered, using various forms of encoding that engages the perceptual-motor system to acquire the information through activity. Enactment of an item, performing a physical movement related or unrelated to the item to be remembered (e.g., rocking the arms back and forth while saying “baby”), has been found to enhance memory for that item compared to just reading a word list of items to be remembered (Engelkamp, 1998). Spranger, Schatz, and Knopf (2008) found an acceleration of recall in participants in the enactment group, suggesting that one of the benefits of enactment is a heightened accessibility of information when there is motor encoding. The question of whether enhanced recall results from merely physical arousal or context-specific movement was addressed by von Essen and Nilsson (2003). Their study examined recall of verbal items in a variety of conditions: one group was merely instructed to remember the verbal item spoken to them, two groups were asked to imagine themselves completing a motor activity related to the item with slight variation in imagery length, while two other groups were asked to either create a physical response to that item or generate the sign for that item in sign language. Results showed that participants in the two motor activation groups experienced

enhanced recall compared to the other three groups. The findings were interpreted to suggest that it is purposeful motor activation that leads to the enactment effect, not just passive imagery, and imply that movement related to the item to be remembered is essential. This motor enactment effect has been documented in persons both young and old (Feyereisen, 2009), as well as in persons with dementia (Lekeu, Van der Linden, Moonen, & Salmon, 2002) and amnesic mild cognitive impairment (Karantzoulis, Rich, & Mangels, 2006). Together these findings demonstrate that individuals with memory impairment have a spared capacity for learning and retaining new motor skills, even in the absence of conscious recollections of ever having performed the task, as illustrated in the case of H.M (Milner et al., 1968). The findings provide hope to caregivers and loved ones that adding meaningful physical engagement to activities of daily living might foster longer independence in persons with dementia.

To date, motor-skill acquisition and retention in patients with dementia have been studied primarily in lab tasks that offer little or no transfer to real activities of daily living. In the present study we examined spared motor function by engaging individuals with Alzheimer's disease in a computer game found in many homes and rehabilitation institutions—the Nintendo Wii™ system. We hypothesized the following:

4. That participants would acquire and retain motor skills in the practiced games because of the physically interactive nature of this gaming system.

5. That the active engagement of the motor system in learning the skills related to the performance of the Wii™ game would facilitate the retention of various cognitive attributes related to the learning experience, such as instruction to participate.
6. That interactions with this gaming system would foster a positive and independent therapeutic environment.

This report describes three case studies that assessed these hypotheses.

METHOD

Participants

The participants were recruited from the local Alzheimer Society concurrent day program for community-dwelling persons with dementia. Consent to participate was given by the persons with dementia and their care partners, because participation depended on attendance to a weekly group, to and from which the care partners were responsible for transportation. Initial and ongoing consent was requested from the persons with dementia to ensure that participation in each session was voluntary.

All participants completed a dementia rating scale (DRS II) administered by the principal investigator, which provides us with an idea of each participant's level of functioning across five measures of cognitive/motor ability, including attention, initiation/perseveration, construction, conceptualization, and memory. Each participant also completed a health history questionnaire in conjunction with the care partner. All personal information was collected during the testing period;

pseudonyms have been used for each of the three participants. At the time of the study, Jeremy was 68 years old with a mixed diagnosis of Alzheimer-type and Lewy Body dementia approximately 2 years prior to testing. Jeremy was the only participant recruited from the early stage support group; he still played in the group environment with his peers. Simon was 79 years old with a diagnosis of Alzheimer-type dementia approximately 5 years prior to testing. Trevor was 90 years old with a diagnosis of Alzheimer-type dementia approximately 3 years prior to testing. Simon and Trevor were recruited from the later-stage support group. Each of the three participants played within their original peer groups for the duration of the experiment. Of note, all participants had a mother with dementia.

Variables

Three variables were used to determine each participant's ability to learn and retain information related to the skill of Wii™ bowling. The first measure was their ability to verbally or physically demonstrate the instructions of how to play the Wii™ game or engage in the game without being given instructions from the experimenter. The second measure was bowling score—the outcome total of their bowling performance provided by the Wii™ gaming system. These measures were used to assess hypotheses 1 and 2. The third and final quantitative measure of learning and retention in this study was Mii™ recognition. This measure reflects the ability of each participant to remember their gaming system character, which they had created to represent their appearance from a

lineup of other Mii™ characters. This measure was also used to assess hypothesis 2. Hypothesis 3 was addressed based on anecdotal observation as well as from feedback provided by the participant and the caregiver.

Protocol

All experimental sessions occurred in the concurrent day program's usual room and time for 1-hour sessions, once a week, across a 9-week term. In addition, Trevor and Jeremy participated in a 5-month follow-up session. Participants spent the first session creating their own Mii's™, which are cartoon characters that represent the player in the Nintendo™ games. Mii's™ can be created to resemble the player by choosing attributes from many different physical characteristics, such as skin and hair color, body shape, adding glasses, facial hair, and so on. Participants were encouraged to create their own characters in an attempt to enhance their familiarity and association with the character throughout the experiment. The remaining time in the first session was spent playing the first game. Wii™ bowling was selected because of the simplicity of playing instructions. All participants played in groups of 2-4, taking turns in a manner consistent with 10-pin bowling. Participants were given the following instructions for playing: squeeze the trigger, pull your arm back, and release the trigger as your arm comes forward. If there were difficulties following these instructions the experimenter would physically assist the participant in completing the movement. All testing sessions began with a recognition test in which the

participant selected their Mii™ from among a lineup of other Mii™ characters and then playing one or two games of bowling. Participants were prompted if they forgot the instructions for the game, but otherwise were encouraged to just play.

RESULTS

Jeremy participated in a total of eight sessions, and the longest period between sessions was 24 weeks. Scores in the bowling game ranged from 71 to 177, a 149% improvement in performance. Four qualitative milestones occurred for Jeremy during testing (at weeks 4, 5, 6, and 24). First, at week 4, Jeremy was able to recognize and select his Mii™ (his individually created character) from a lineup of other Mii's™ on the screen. Second, at week 5, Jeremy played the game in the absence of any instructions from the experimenter. And in week 6, Jeremy explained, in detail, the instructions for playing the video game to a new member of the program. At week 24 Jeremy not only recorded his highest bowling score to date, but also was able to explain in detail how to play Wii™ bowling. When Jeremy was asked to explain how to play the game to newcomers in the group, he began by describing the function of the trigger and directional buttons on the controller, and continued with a demonstration of how to bowl. Throughout the game Jeremy also provided tips and feedback about how to enhance performance. Following is an example of a session in which Jeremy was able to verbalize feedback and instruction in his peer group.

[Experimenter asks Jeremy to tell the new people in the group how to play the bowling game.]

Jeremy: this moves that line the other way (explaining control buttons), this brings it wherever you want it to hit the pins … see … it goes both ways. Now, what you do is you push this down and bring your hand back and before you come forward you let this thing go.

Experimenter: not that top one, the one on the bottom.

Jeremy: right … you push that when you bring it back, and when you let it go, throw it.

Jeremy also participated in a skill training session for the bowling game (a subset of activities designed to improve specific skills related to Wii™ bowling), resulting in a score range for manipulating force of bowl of 428-483 pins. This manipulation of force of bowl is related to the speed with which the remote is brought forward, in a swinging movement by the player, directly effecting speed and force of ball movement in the games. Different combinations of pins in the alley require different speeds of ball throw to knock down; therefore, this skill requires learning and adaptation. Jeremy had a DRS II score of 128 (see Table 1).

Simon participated in a total of seven sessions. The longest period between sessions was 14 days. Scores in the bowling game ranged from 86 to 107, with the highest score occurring on the first day of testing. Simon was not able to recognize his own Mii™. At the sixth and seventh week Simon was able to play the game in the absence of instruction from the experimenter, but was unable to verbalize instructions to other members of the group. Simon had a DRS II score

of 68 (see Table 1 for breakdown of score). After a 6-month break in playing the Wii™, Simon participated in the game off-site (with family) and the spouse reported Simon's score as 138. Trevor participated in a total of five sessions. The longest period between sessions was 22 weeks. Scores in the bowling games ranged from 86 to 116, with the highest score occurring in the second session and the second highest at the 5-month retention interval. At the third and fourth week Trevor could play the game in the absence of instructions from the experimenter, and was able to recognize his Mii™. At the week 22 retention test Trevor was able to play the game in the absence of major instruction (e.g., not all steps of performance had to be repeated; only one was given as a reminder). Many other observations, not easily quantifiable, were recorded during these practice sessions and will be described qualitatively. Participants with prior bowling experience would often use bowling-specific technical terms such as “split,” “turkey,” or “gutter ball.” This terminology was not present on-screen in the game or prompted by the experimenter in any way. Participants with bowling experience also adopted a particular bowling stance that was characteristic of experienced bowlers. Once again this is a game-specific behavior that was not prompted by the testing scenario, and assumed to have been retrieved from long-term memory associations with the sport.

Participants also began providing feedback concerning other players' form, strategy, and playing style by the second week of testing. This is not a new phenomenon in the group because feedback is encouraged and reflects normal

communication among the participants during their daily interactions. They are encouraged to help one another; each person's strengths or previous life experience with a topic or task is frequently called on. This feedback was only one aspect of each participant's engagement in the group environment. Participants would cheer on each other, keep count of pins, and make comments on performance from one turn to the next. This spanned not only each testing session but also week to week. Participants would enter the group each week motivated and prepared to play the Wii™ game.

DISCUSSION

We began this experiment with three hypotheses. The discussion of results will be centered on support or refutation of these statements.

1. That participants would acquire and retain motor skills in the practiced games because of the physically interactive nature of this gaming system.

Bowling scores and retention periods reflected a wide range of performances and learning of the Wii™ bowling task. For persons with dementia, just the act of engaging in the game, by following rules and instructions to execute actions, represented a challenging task. Regardless of changes in game score, continued interaction with the game itself was an achievement of memory. This required participants to recall procedural knowledge and the order and sequencing of motor actions to complete the task on a short-term basis from one turn to the next and on a longer-term basis from one week to the next. Optimizing that procedural knowledge to improve performance and increase scores successfully

reflected motor learning.

2. That the active engagement of the motor system in learning the skills related to the performance of the Wii™ game would facilitate the retention of various cognitive attributes related to the learning experience, such as instruction to participate.

The participants demonstrated many qualitative features of memory—those items relating to the participant's familiarity with the game, environment, and rules. Mii™ reflected a more general embodiment with the game, and, therefore, is included in the qualitative component of the discussion. We selected Mii™ creation and recognition in an attempt to enrich the encoding experience of game participation, and provided an external reference for each participant's prior experience with the game. None of the participants were able to consistently select their Mii™ out of a list of other characters.

Another cognitive component of these sessions was the language used to call shots, encourage players, and refer to scores. The use of task-appropriate language and posturing were considered to reflect motor “priming.” Traditionally viewed as the beneficial effect of observing an action before performing it (Stanley & Miall, 2009), here we considered priming as movement-triggered memories of the bowling experience, such as bowling-specific terminology and stance. The immersion in the bowling experience appeared to trigger memories for the game, unlocking a familiarity with activities, words, and behaviors related to previous bowling experiences. In what we assume would be the absence of

being able to specifically generate this information on request, based on the observed word-finding difficulties of these participants, they “remembered” information relating to the game once play was underway (in this experiment participants were not asked to do this, but based on performance within the group we assumed that verbal generation of game specifics would have been unlikely).

3. That interactions with this gaming system would foster a positive and independent therapeutic environment.

Performance-related feedback shared between participants provides useful information to the experimenter because it opens a window into the depth and scope of each individual's understanding of the game. Subtleties in playing the Wii™ bowling game, such as the position of arm or speed of swing, provided an advantage for performance when using the remote because of its strong simulation of actual game play. Participants picked up on these nuances of performance and encouraged one another with useful tips for performing the bowling game, such as “straighten your arm” or “release the trigger faster.” Jeremy was better able to verbalize these instructions, although Simon and Trevor, who experience more intense word-finding difficulty, still managed to communicate their point through demonstration or longer explanations. These observations imply that our participants, regardless of whether they were able to verbalize all the rules of the game, were indeed comprehending the requirements and were able to troubleshoot performance issues.

One final observation was related to the opinion of the care partners on their spouse's participation in the game. It was often the case that care partners would comment that their spouses were excited about playing again or had told family members about their performance in the game. Each participant's involvement in both playing the game and being part of the study became a topic of conversation; an item that they could speak to loved ones about with authority. This, in itself, reflected another positive result of the study.

The training protocol used in this study does not replicate exactly the methods used by Dick and colleagues in their continuous or variable training. The training here could be described more as a type of constant practice, because only the game of bowling was played during training sessions and actions were fairly repetitive, each of the 10 turns to play required bowling a ball in the same context. This supports other studies (e.g., Dick et al., 1996, 2003), which have found interference to be detrimental to learning in persons with memory impairment and/or dementia. This study also demonstrated a role for purposeful or related physical activity, similar to the claims of studies discussed at the start of this article (Engelkamp, 1998; von Essen & Nilsson, 2003). The bowling movements required for the game were almost identical to those required in real-life (as opposed to virtual) bowling, which we believe may play a role in enhancing memory for that action.

CONCLUSION

Three case studies provide a window into the realm of what is possible for

persons with dementia. The goal of this study was to explore what the introduction of the game Wii™ bowling would do in the group environment. The findings were that playing a Wii™ game was an engaging group activity—participants were able to follow the rules and play the game, improving or maintaining performance up to 5 months. The retention period successfully achieved in this study is quite long in the context of motor task research involving persons with dementia. Overall the game provided a realistic motor task that all clients could complete, regardless of condition, and became a valuable part of their therapeutic environment. These results also imply a role for motor engagement in enhancing memory or familiarity with a task, suggesting that these spared motor abilities may be a hidden resource that can benefit persons with dementia. In the simplest form, this study provides evidence that the Nintendo Wii™, and other such physically interactive gaming systems, can be used in recreational therapy to engage persons with dementia.

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Figure Captions

FIGURE 1 This graph presents 10-pin bowling scores during the initial 9 week training session, and at the 5-6 month (31-33 week) follow up. All participants demonstrate improvement during training, and sustained (or improved) performance at retention testing.

TABLE 1 Dementia Rating Scale (DRS II) Scores

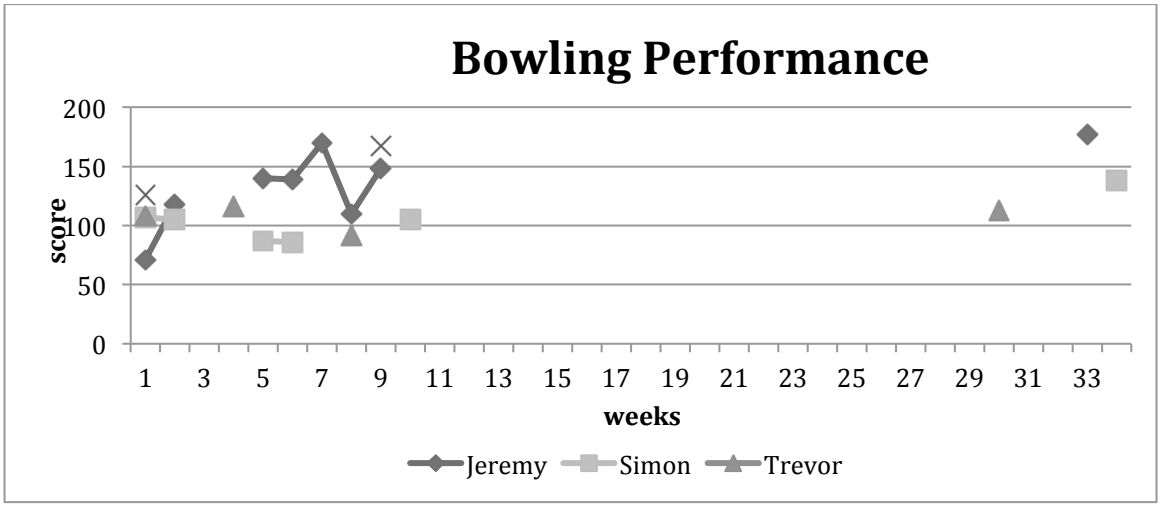

FIGURE 1 This graph presents 10-pin bowling scores during the initial 9 week training session, and at the 5-6 month (31-33 week) follow up. All participants demonstrate improvement during training, and sustained (or improved) performance at retention testing.

Table 1

DRS II Scores

	Simon			Trevor			Jeremy			Avg. AD Score
Measures	Raw Score	AMSS	%ile Range	Raw Score	AMSS	%ile Range	Raw Score	AMSS	%ile Range	Raw Score
Attention	33	8	19-28	33	9	29-40	37	13	82-89	23.55
Initiation/ Perseveration	6	2	<1	20	3	1	35	8	19-28	21.37
Construction	5	7	11-18	6	10	41-59	6	10	41-59	2.55
Conceptualization	16	2	<1	33	9	29-40	35	8	19-28	21.18
Memory	8	2	<1	13	3	14-15	13	2	<1	10.91
Total Score	68	2	<1	105	3	1	126	5	3-5	79.55

AMSS -Age Correlated MOANS Scaled Score

General Discussion

The research described in this thesis was designed to explore and advance the body of evidence supporting a separable motor memory system, and its role in behavior and learning. This was attempted through three experiments ranging in behavior from motor performance to learning, examining the role of motor information in online control of balance, learning a motor communication task, and new motor learning in persons with dementia.

There are three main themes that surfaced from the three manuscripts included in this work.

1) Multi-sensory information can be redundant.
2) Motor information can be compensatory.
3) Motor information most beneficial when actively engaged.

These themes will be discussed with evidence from each of the different but complimentary experiments that comprise this thesis.

1. Multi-sensory information can be redundant

Multi-sensory information can be redundant (Jeka, Oie, & Kiemel, 2000) and how the body differentiates between these sensory inputs is not well understood. Work examining unreliable vision versus no vision conditions has found that balance is worse with partial but incorrect visual information (Vidal et al., 1982) suggesting that the nervous system cannot ignore even inaccurate sensory information (Jeka, Oie, & Kiemel, 2000). This multi-sensory redundancy may explain findings in both the light touch and sign language studies.

There were two non-significant results in the light touch study that may be better understood in the context of multi-sensory redundancy: no effect of light touch and no effect of timing. There was no significant benefit of light touch in either tandem or one-foot stance with vision compared to control trials. This suggests that there is no added benefit of motor information, via light touch, in the presence of vision. No significant effects of timing suggest that motor information in short duration light touch does not provide event related reduction of sway, but does indicate general information about the body's position in space. This would support the claim of Reginella, Redfern and Furman (1999) that light touch, of any duration, provides sensory information used to form an accurate sense of spatial orientation. If this statement is true we can assume that motor and visual information about sensory orientation was in this case redundant.

The redundancy of multi-sensory information may also apply to learning. Multi-sensory redundancy may explain the lack of enactment effect in the younger adults in the sign language study for number of items recalled. In highly functioning systems, information from each sense may be highly redundant, and might account for the ceiling effect at learning in the younger adults. Participants in the enactment group received no significantly greater benefit from enacting the signs for number of items recalled then from the recognition group who only visually experienced the signs. The absence of a difference between recognition and enactment suggests that the type of information these participants were using to acquire this information may have been similar.

2. Motor Information can be compensatory

If multi-sensory information is redundant in these cases, this evidence supports the claim that motor information can compensate for other senses when they are removed, challenged or impaired. The role of motor information as compensation for a removed, challenged or impaired sense is supported by results from the light touch study, the sign language study and the Wii study.

In the light touch study there was a trend towards an increased benefit from light touch with increasing difficulty of visual condition (eyes closed). The increased benefit of light touch in absence of vision suggests that motor information is able to provide compensatory information about the body's position in space. This compensatory role of motor information goes hand in hand with the assumption of multi-sensory redundancy in this task, discussed above.

In the sign language study we assessed the effect of enactment across the lifespan in an attempt to parse out any age related differences in benefit of enactment or age related changes in performance. As previously discussed there was a significant difference between groups for rate of forgetting in both the young and older adults. The enactment group experienced enhanced recall at retention. There was also a significant age by enactment interaction effect. These data suggest that the cognitive challenges that are a natural part of the aging process may lead to the recruitment of motor information as a compensatory strategy in learning and memory. For the older adults, visually studying an expert performance of a hand shape was not equivalent to personally performing the

hand shape. Older adults showed a trend toward better strength of memory with enactment, i.e. participants in the enactment group retained a greater percentage of initial learning at retention compared to those in the recognition group. The recognition group learned a greater number of signs initially, but experienced a significantly greater rate of forgetting compared to the enactment group. The greater strength of memory for items learned in the enactment group support the claim that enactment is a result of an enriched encoding environment, and motor information is the most efficient of these methods of encoding (Nilsson, 2000).

The results of the Wii study also support a compensatory role for motor information, but this time in a system that is clinically impaired. Participants in the Wii study all had a dementia diagnosis; meaning that they had clinically impaired short-term memory, verbal memory and word finding. Participants were physically engaged, and verbal instructions were paired with guided movements to provide context. The protocol was structured to use motor information as compensation for verbal memory and traditional cognitive strategies for learning. Two of the three participants were not able to verbalize instructions, but were fully capable of physically demonstrating successful performance. Participants were able to learn how to Wii bowl using this methodology, supporting claims that motor information can compensate for impaired function, and that motor capacity itself is spared in these clinical conditions, enabling learning.

3. Motor information is most beneficial when actively engaged*.*

The final theme of this discussion is that motor information must be experienced physically to provide the greatest benefit. This claim is supported by all three studies in this document.

In the light touch study we compared the effect of a light breeze to control and light touch trials. The breeze condition was included to determine how light a touch, or sensation, could be used to benefit sway. There were no significant differences between the breeze and control conditions. This suggests that a light breeze on the skin surface was not sufficient to provide a type of sensory motor feedback of the body's position in space. This finding supports the role of actual touch, either person to person or person to object, in order to have any improvements in balance. The actual requirement of physical touch strengthens the claim that it is the motor information, processed and integrated separable from other senses that drives the benefits associated with light touch.

In the sign language study the trend towards an effect of enactment in older adults supports the claim that visually experiencing a motor action is not the same as physically engaging in that action. The enhanced effect of motor action is also supported by the significant differences in rate of forgetting which suggest a greater strength of memory with enactment for both young and older adults. There appears to be a greater benefit to physically engaging in this task compared to visually studying the action of an expert performer for retention. Whether this is due to the compensatory nature of motor information, in these

age groups and for this task, or enriched encoding, physical engagement is what appears to make the difference.

Anecdotally, in the Wii study, it was noted that it was not sufficient for participants to observe someone else completing the physical actions required to bowl. The participants themselves needed to engage in the task in order to understand and replicate successful performance. The improved or maintained performance at retention is attributable to the motor memory resulting form this physical engagement at learning.

The role of motor information in behavior and learning is truly complex. Whether we attribute its effects, or in some cases no-effect, to multi-sensory redundancy, the presence of sensory or cognitive challenges, or enriched encoding from physical engagement in a task, we cannot deny it is a valuable source of information across the lifespan.

Conclusion

These studies support the claim that there is a separable motor memory system. This system appears to be most relevant in the presence of physical or cognitive challenge improving or maintaining performance in a compensatory capacity. This work also supports findings that this motor system is spared in memory impairment and dementia, highlighting motor learning as a unique avenue through which to improve learning and memory in disease.

Future study exploring the potential benefits of short duration light touch on balance quantifying the incremental increases in benefit related to increase in

difficulty of stance. Examining the role of short duration light touch on persons with congenital or acquired blindness may help improve our understanding of the motor information of light touch and it's role in the complete absence of vision. Work has already been done using motor cues for navigation in persons with dementia, attempting to leverage any spared capacity for this stream of information to maintain independence in community dwelling seniors (Grierson, Zelek, & Carnahan, 2009). Another avenue to explore is the role of self-control in administration of light touch for balance, and how that control may modulate the effect on sway.

Examining the expanded retrieval errorless learning paradigm in persons with Alzheimer Disease could explore the limits of this spared motor learning capacity. Utilizing a motor communication task, such as the American Sign Language used in this manuscript, could have significant therapeutic implications. If persons with Alzheimer Disease were able to learn a motor communication task via a system that is spared from disease related neuro-degeneration, it could extend the quality and quantity of communication later into the disease. The enactment effect has been found to have no correlation with intelligence (Cohen & Bean, 1983), this carries with it serious implication for the benefits of pairing physically engaging activity with items to be remembered across many healthy and impaired populations. In these populations there may be a reconsideration of the Fitts and Posner learning model, with an adaptation

of stage one which allows for the external storage or pairing of information with motor cues to compensate for disruptions in short term memory capacity.

The final experiment of this manuscript confirms the benefits of physically engaging activity in learning new tasks in persons with dementia. By exploring the spared capacities of persons with dementia a whole new realm of activities and abilities has been opened. It is unlikely that enactment will slow or retard the progress of dementia, but it may act to improve the quality of memories for enactment-encoded items, increasing the amount of time persons with dementia can be independent and engaged in their community. Future work should examine the use of paired physical enactment with activities of daily living, and other more relevant behaviors that may influence independence and quality of life in persons with dementia.

Overall the opportunities for utilizing motor information for behavior and learning are vast. The use of motor information, such as light touch, has important implications on the rehabilitation of motor functions in persons with disease and traumatic injury. The enactment effect can be exercised for persons across the lifespan, including those with cognitive and memory impairments, to improve learning and memory. Increasing our understanding of the role of motor information in behavior, learning and memory will expand our knowledge of these processes on the whole. The ability to dissociate how our nervous system unravels and processes unique sensory inputs, and how this information can be

stored and used for future use, is one of the main challenges in understanding the brain.

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