

Examining the effects of different model types on consolidation and motor learning

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## Abstract

It has been shown that the observation of two model types, or mixed-modeling, is more beneficial than watching a single type alone (Andrieux & Proteau, 2013; Robertson, 2015). Furthermore, observing others has been shown to lead to consolidation, however, the distinct behavioural outcomes are different than those following physical practice (Trempe et al., 2011). To date it is unknown, whether the observation of different model types, when interspersed with physical practice, will affect the amount of consolidation that occurs. The purpose of this research was to attempt to replicate the mixed-model benefit and to determine whether a mixed-model observation intervention would affect consolidation processes differentially compared to a single-model type alone. Forty-five university age students were randomly assigned to a mixed-model (MM), unskilled model (UM), or skilled model (SM) observation group. All participants were required to learn a waveform-matching task, in which they used their non-dominant arm to reproduce a waveform as accurately as possible within a goal movement time of 900ms. The experiment comprised three testing sessions. The first session required participants to complete a pretest, where they performed 10 trials of the skill with no knowledge of results (KR) provided. Following this, they did their first acquisition session where they received KR on all trials and performed nine blocks of 10 trials that consisted of six physical practice interspersed with four observation trials. Ten minutes following this session, participants performed an immediate retention test consisting of 10 no KR trials. The next day began with a delayed 24hr retention test of 10 no KR trials and another acquisition session. One week later, participants performed 10 no KR retention trials 10 transfer trials, in which participants reproduced a slightly different waveform under a goal movement-time of 1150ms. Root mean square error (RMSE), temporal accuracy and spatial accuracy were collected as dependent variables. Acquisition results

demonstrated that all video conditions acquired the skill similarly in terms of all dependent variables. Retention results indicated a significant group by time interaction over the 24-hour retention interval ( $F(2, 42) = 3.809, p = .030$ ), which showed that those in the MM group were significantly better at the 24-hour retention compared to the other groups, however, this mixed-model benefit was no longer seen at the weeklong retention. In conclusion, these results suggest that mixed-model observation is beneficial to motor learning at the 24-hour retention, in terms of temporal accuracy and also that mixed-model observation could potentially lead to enhanced consolidation of a motor skill.

## Acknowledgements

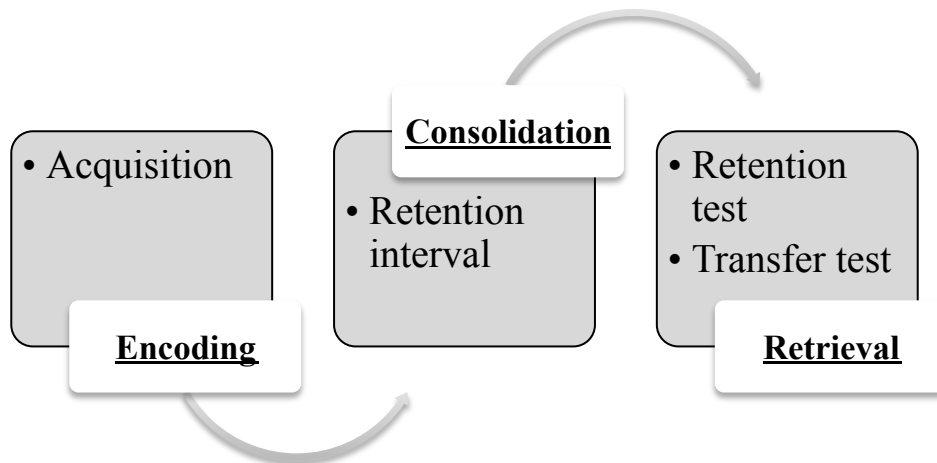
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## **Chapter 1: Introduction**

Motor learning is defined as a set of processes that lead to relatively permanent changes in one's skilled movement as a result of practice or experience (Schmidt & Lee, 2011). Every person in the world has engaged in these processes, whether learning to walk, use a tool, kick a soccer ball or play the piano; these are all examples of skills that require motor learning. Unfortunately, we cannot learn these motor skills without practice and experience; two actions that help us create motor memories. The formation of motor memories involves three distinct stages: encoding, consolidation and retrieval (Robertson, 2009) and have been examined within the motor learning paradigm (refer to Figure 1).

The first stage of memory formation is the encoding stage, which occurs during acquisition as the learner practices a motor skill. Results from acquisition tell us how well the participant performed the skill during practice, with an intervention; however, they do not demonstrate relative permanence of the skill (Schmidt & Bjork, 1992). Although a participant may perform very well during acquisition, this performance can be transient. Therefore, it is important to have a retention (or transfer) test to examine the permanent learning effects that occur due to practice (Schmidt & Bjork). Between the acquisition and retention tests, consolidation processes help to preserve the motor memory for the long-term. The period of time between acquisition and retention is defined as the retention interval and it can span from 5 minutes to several years. Finally, during a retention (or transfer) test, the learner retrieves the motor memory in order to produce the desired movement (Kantak & Winstein, 2012). The results from a retention (or transfer) test demonstrate whether the benefits shown during the acquisition phase are carried over to a situation when practice, and the intervention of interest, are not present. Thus, the retention (or transfer) results are used to determine whether an intervention was beneficial to motor learning. In the proposed experiment, I plan to investigate

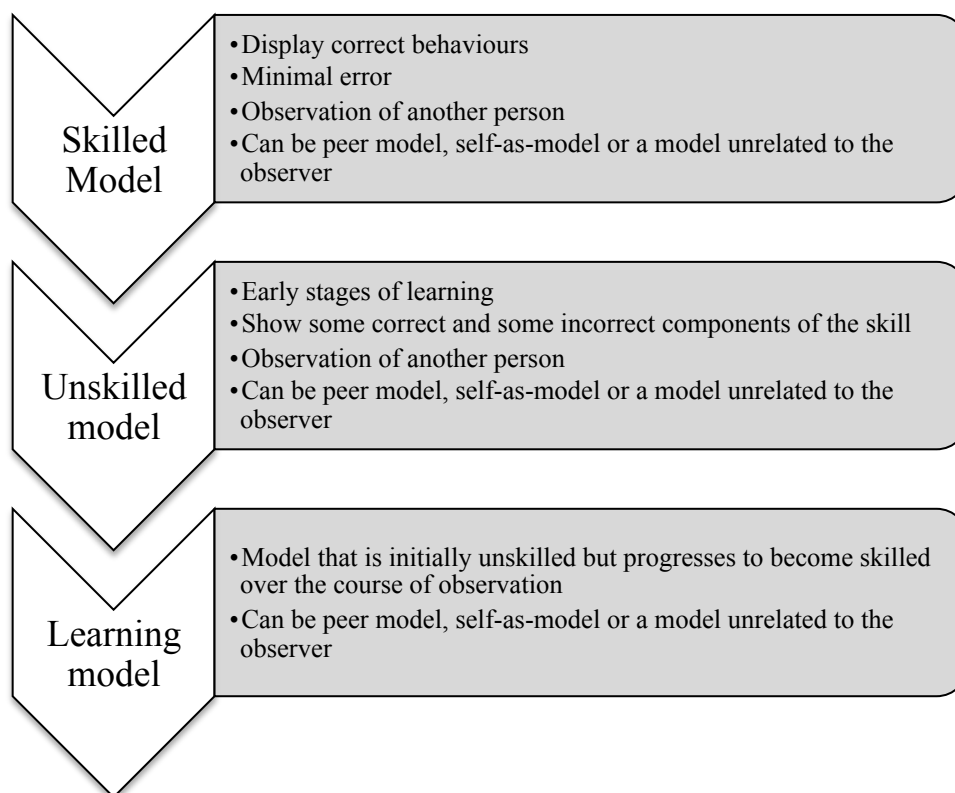
the consolidation phase in the formation of motor memories and show how a motor learning intervention might affect consolidation.



*Figure 1.* The relationship between the three stages of motor memory formation (encoding, consolidation, retrieval) and segments of a motor learning paradigm (acquisition, retention interval, retention/transfer tests).

The motor learning intervention to be examined is that of observational learning, which is a process that allows learners to acquire the capability to perform an action by observing the self, or others (Starek & McCullagh, 1999; Schmidt & Wrisberg, 2008). It has been shown that there are several model characteristics that influence the effectiveness of observation, such as age, gender and skill level (Meaney, Griffin & Heart, 2005). For the following research, the characteristic of importance is skill level. For this characteristic, two levels of interest are skilled and unskilled models (refer to Figure 2). Skilled models are those that display the correct behaviours to be later performed, whereas unskilled models display the skill in the early stages of

learning, thus both correct and incorrect components of the skill are shown. It has been shown that both skilled models (Al-Abood, Davids, Bennett, 2001; Heyes & Foster, 2002) and unskilled models (Buchanan & Dean, 2010; Lee & White, 1990) are effective for motor learning.



*Figure 2.* Key characteristics of different model types. *Note:* if a skilled model is referred to, for example, one can assume that it is either a peer model, or a model unrelated to the observer. If a self-as-model is used it will always be explicitly stated.

Although skilled and unskilled models are both beneficial to motor learning, they have been argued to be advantageous for different reasons. Given this, it has also been proposed that combining two model types, termed mixed-modeling, could cause additive benefits (Rohbanfard & Proteau, 2011; Robertson, 2015). Indeed, Robertson (2015) demonstrated that a mixed-model intervention (self-observation and skilled model) was more beneficial to motor learning than

only self-observation (technique of watching oneself on video). It is important to note that when someone is engaging in self-observation they are essentially observing a model at the same skill level as themselves, therefore in Robertson's research the self-observation group would have been akin to a unskilled model. In that research, there was also the suggestion that the benefits seen for the mixed-models intervention may have been related to enhanced consolidation processes; those motor memory processes that help with the transfer of information into long-term memory (Trempe, Sabourin, Rohbanfard & Proteau, 2011).

Recently, three research groups have investigated whether consolidation can occur following observation of a motor skill (Trempe et al., 2011; Van der Werf, Van Der Helm, Schoonheim, Ridderikhoff & Van Someren, 2009; van Schalkwijk et al., 2015). It has been determined that consolidation does occur following observation, although the distinct behavioural outcomes are slightly different than those occurring following physical practice (Trempe et al., 2011). Since consolidation occurs following observational learning, and it is not fully understood why mixed-models are beneficial, it would be interesting to investigate if a mixed-model observation intervention would be more advantageous to consolidation than a skilled model or an unskilled model intervention alone; which will be the objective of the proposed research.

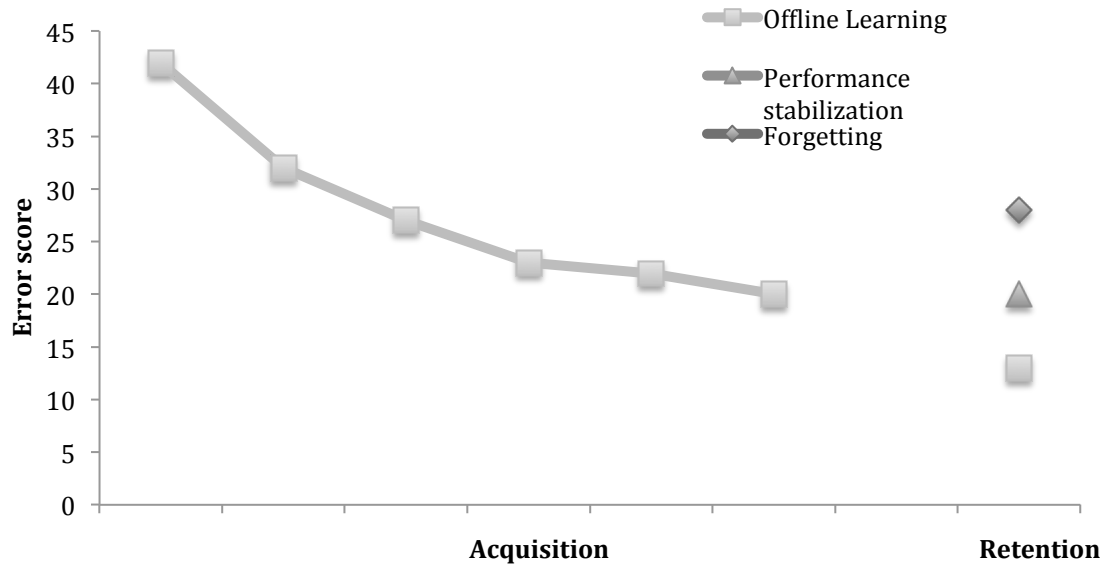
In the upcoming literature review, I begin by explaining the two behavioural outcomes of consolidation and several different factors that can affect consolidation processes. I proceed to introduce the research that has been done regarding the effects of observation on consolidation, noting the gaps, and then proceed into the observation literature. In the observation section, I discuss the different model types implemented in the research design (peer-skilled model observation, peer-unskilled model and mixed-model observation), how these models might affect

motor skill consolidation, and highlight the gaps pertaining to this research. Finally, I conclude with the research questions and hypotheses of the research undertaken.

## **Chapter 2: Review of Literature**

The term consolidation was coined over 100 years ago as a declarative memory's "resistance to interference from competing memories" (Müller & Pilzecker, 1900). Some of the earliest consolidation experiments, done in 1949, demonstrated that when rodents were given electroconvulsive shock treatment after acquisition, it greatly impaired their retention. These results indicated that the electroconvulsive shock disrupted the consolidation processes that normally occur following acquisition. This also demonstrated that consolidation was crucial to learning; if consolidation was impeded then learning would not occur (McGaugh, 2000). These early experiments initiated further research, and consolidation is now considered to be a post-acquisition process where memories become more stable and are transferred into long-term memory with the passage of time (Kantak & Winstein, 2012; Trempe et al., 2011).

Since that seminal work, it has been shown that similar consolidation processes occur in humans as those of animals. For example, it was shown that repetitive transcranial magnetic stimulation (rTMS) applied to the primary motor cortex immediately after acquisition of a newly learned ballistic pinching movement caused impaired retention. If rTMS was applied six hours after the acquisition session, however, there was no effect on the performance in retention (Baraduc, Lang, Rothwell & Wolpert, 2004; Muellbacher et al., 2002). This clearly demonstrated that interference during the time following the acquisition period, a time in which consolidation processes are assumed to occur, affected learning. Therefore, consolidation is considered a very important process for motor learning. Thanks to further research, it is now known that motor skill consolidation has two distinct behavioural outcomes: performance stabilization and offline learning (Kantak & Winstein, 2012; Trempe et al., 2011).



*Figure 3.* The potential changes in behaviour following a retention interval, offline learning and performance stabilization are potential indicators of consolidation. The light grey square represents offline learning and shows an improvement in performance between practice sessions. The medium grey triangle shows performance stabilization in that there was no significant change in performance following the retention interval. The dark grey diamond represents some forgetting, in that the participant did not retain the skill gained from the previous practice session.

### **Performance stabilization**

After the acquisition phase of learning there is a time-window where the newly acquired memory can be disrupted by another competing memory, however, with the passing of time this new memory will become more stable and less susceptible to interference (Krakauer & Shadmehr, 2006). This time-window is considered to be the consolidation interval during which stabilization processes take place, helping to create lasting memories that are resistant to interference (Walker, 2005). In reference to Figure 1, performance stabilization would unfold

during the retention interval, and a retention test and/or transfer test would give evidence that the motor memory of the task endured.

Brashers-Krug and colleagues (1996) first demonstrated performance stabilization in their experiment in which they manipulated the time course associated with learning two motor tasks. All participants, except the control group, were required to learn two different motor skills (task A and task B) with varying amounts of time in between the acquisition sessions. The control group simply learned task A and performed the retention test 24-hours later. It was found that those in the control group showed retention of task A. Meanwhile, those who learned both tasks in close succession did not retain task A, suggesting that learning task B disrupted retention of task A (retroactive interference). However, with a four-hour delay between learning task A and task B, no differences in retention, as compared to the control group, were found. Such findings indicated that the four-hour delay enabled consolidation of task A to have occurred. Therefore, Brashers-Krug and colleagues concluded that the evolution of a motor memory continues after practice ends, at least up to four hours, allowing the memory traces to become strengthened and immune to interference (Brashers-Krug, Shadmehr & Bizzi, 1996). Since 1996, performance stabilization has been demonstrated in many studies, most often in motor adaptation paradigms (Krakauer, Ghilardi & Ghez, 1999; see Krakauer & Shadmehr, 2006 for a review). Performance stabilization is not the only behavioural outcome of consolidation; the second outcome is often called performance enhancement or offline learning. In the remainder of this document, offline learning will be used.

### **Offline learning**

Offline learning is the spontaneous improvement in performance that occurs between acquisition and retention (during the retention interval), without any further physical practice

(Kantak & Winstein, 2012). In keeping with Figure 1, offline learning would occur during the retention interval, only to be revealed through retention and or transfer test performance. Karni and Sagi (1993) showed offline learning using a visual discrimination task. Throughout the first few blocks of acquisition the participant's performance improved, then it leveled off and became more stable and no amount of practice affected this trend. However, the learning curve continued to improve when comparing results from subsequent daily practice sessions. To follow the time course of this change, retention tests were performed 20 minutes to ten hours after the initial training session. They found that there was no improvement when testing during the first eight hours following acquisition, however, after eight hours some participants showed improvement in performance and the next day all the participants showed large improvements. Karni and Sagi (1993) were the first to document that not all human learning is concurrent with practice and that there are processes that occur during the retention interval that can cause improvements in performance.

Since 1993, many researchers have demonstrated offline learning, not only with visual discrimination tasks or perceptual skills, but also with motor skills. For example, when participants trained short sequences of finger movements there was the same offline improvement in performance as was seen with perceptual skills (Albouy et al., 2013; Fischer, Hallschmid, Elsner & Born, 2002; Walker, Brakefield, Morgan, Hobson & Stickgold, 2002). Offline learning has also been demonstrated in motor adaptation paradigms (Doyon et al., 2009; Trempe & Proteau, 2010) and gross-motor tasks (Malangré et al., 2014). The fact that offline learning is a behavioural outcome of consolidation is fairly undisputed, however, some researchers maintain that offline learning is dependent on sleep while others disagree (Walker, 2005).

## **Sleep and consolidation**

A great amount of consolidation research to date has investigated the role of sleep in memory consolidation and many of the results have been contradictory. For example, some researchers have found that offline learning can occur with and without sleep (Fischer et al., 2002; Wilhelm, Metzkw-Mészáros, Knapp & Born, 2012), while others have found that sleep had no effect on offline learning (Cai & Rickard, 2009). More notably, many studies have found that sleep causes better consolidation outcomes than no sleep (Borragán, Urbain, Schmitz, Mary & Peigneux, 2015; Hill, Tononi & Ghilardi, 2008; Walker, 2005). Importantly, it has never been shown that sleep interferes with, or inhibits, consolidation processes; rather, sleep is either not required or it is beneficial to learning. Therefore, the experimental protocol of this research used a 24-hour retention interval that included a sleep cycle.

## **Skill type and consolidation**

Ten years ago, it was thought that the findings regarding performance stabilization and offline learning could have “important implications for the efficient learning of *all* skilled actions in humans” (Walker et al., 2002, p 205). Unfortunately, there is little evidence to support this claim as the majority of consolidation research has been done with only a limited amount of tasks, namely serial reaction time tasks (SRTTs), finger-tapping tasks, motor adaptation tasks (Malangré et al., 2014), and only a handful of studies used gross-motor skills (Schmidt, Erlacher, Blischke, Brueckner & Müller, 2010; Trempe et al., 2011). For example, Schmidt and colleagues (2010) asked participants to learn a sequence of unrestrained arm movements to touch rectangles on a smartboard, as fast as possible. In this particular study, the researchers failed to see any behavioural outcomes of consolidation (Schmidt et al., 2010). Malangré et al., (2014), however, found that in a more complex movement sequence, requiring participants to perform unrestrained

arm movements, the participants showed offline learning. Further to this, Trempe and colleagues (2011) found that both offline learning and performance stabilization occurred after participants performed a knockdown barrier task – a series of arm movements to knock down barriers in a set amount of time. These three studies have varying results; therefore, whether consolidation outcomes occur following the acquisition of gross-motor skills is an area that requires further investigation. Consequently, we decided to use a waveform task to continue to explore the consolidation of gross-motor skills. Another area that requires more investigation is how consolidation can be affected by different methods used for motor skill acquisition, with observational learning as the method of interest in this research.

### **Observation and consolidation**

Although many studies have investigated the behavioural outcomes of consolidation following physical practice of a motor skill, there is relatively little research regarding any other methods of motor skill acquisition and their effects on consolidation. For example, motor memories can be induced by simply observing someone perform an action (Stefan et al., 2005). Action observation is an alternative mode of learning motor skills, and, to our knowledge, its relation to consolidation has been investigated in only three separate studies (Trempe et al., 2011; Van der Werf et al., 2009; van Schalkwijk et al., 2015).

Van der Werf et al. (2009) implemented four experiments to investigate consolidation occurring after observation of a finger-tapping task and how the timing of sleep affected consolidation. In all the experiments, participants were required to observe a video of an unskilled model performing the skill. In the first experiment, participants were allowed to move their fingers in order to receive motor feedback during the observation session; however, they were not allowed to practice the actual sequence. In the three experiments that followed, Van der

Werf and colleagues eliminated the finger movement, and examined whether the observed offline learning was due to familiarity with the finger-tapping sequence. They also included a manipulation to investigate whether there were differences between observing in the evening versus the morning. The overall finding from Van der Werf et al.'s study was that sleep, soon after observation, seemed to be required for offline learning to occur (Van der Werf et al., 2009).

Several years after this initial observation and consolidation study, van Schalkwijk and colleagues (2015) did a similar study in which they examined whether children could learn a finger-tapping task through observation and if, similar to the experiment with adults (Van der Werf et al., 2009), they required immediate sleep. In van Schalkwijk and colleagues' experiment, participants were not allowed to move their fingers throughout the observation session and an unskilled model was used. Although it was found that observational learning did not generate offline learning, the immediate sleep after observation prevented a performance reduction during retention. As such, performance stabilization was demonstrated.

Finally, Trempe and colleagues (2011) investigated whether observation of a skilled person performing an arm movement to knock down barriers in a certain amount of time could result in offline learning and performance stabilization. In the first experiment, participants observed 40 trials of the knockdown barrier task and were given feedback regarding the movement timing of each trial. The participants were not allowed to move throughout the observation session. The results showed no differences in retention when comparing a group who performed their retention test five minutes after observation and a group who did retention 24 hours after observation, therefore indicating there was no offline learning.

A different paradigm was used in experiment two, as participants observed two sequences (A and B) either ten minutes apart or eight hours apart. Under these conditions, it was

found that those in the eight-hour group were significantly less accurate on their retention of sequence B, compared to the five-minute group. These results indicated that in their eight-hour interval between observation of sequence A and B, they were able to consolidate and stabilize sequence A, which caused interference on the learning of the second sequence. Thus, Trempe and his colleagues concluded that observational learning of a motor skill leads to consolidation, but results in different behavioural outcomes than when a motor skill is physically practiced. That is, Trempe and colleagues did not show any offline learning following observation, yet it has been shown for physical performance (Albouy et al., 2013; Fischer et al., 2002; Malangré et al., 2014). Additionally, for performance stabilization, observational practice showed that sequence A interfered with the learning of sequence B, whereas in experiments where the skill in physically practiced, sequence B interferes with sequence A.

Considering the fact there is little research regarding the effects of observation on consolidation, there are, at least, two notable gaps in the observational learning and consolidation literature. The first area warranting investigation is whether the type of model being observed has an effect on the consolidation outcomes. Many researchers interested in observational learning have been interested in ‘who’ is the most beneficial model to observe when trying to acquire a motor skill (see Ste-Marie et al., 2012 for a review), but few have considered what models should be combined for more effective learning. Secondly, as Trempe et al. (2011) noted “further work is necessary to determine whether physical practice following observation (and vice versa) interferes with consolidation processes” (p 191). Therefore, in our experiment we investigated consolidation under conditions in which observational and physical practice was interspersed during the acquisition of a motor skill.

## **Observation and motor learning**

Observational learning is defined as the process through which learners acquire a skill by observing the self or others striving to perform novel behaviours and improve actions (Starek & McCullagh, 1999). Bandura was one of the first people to claim that observation was one of the most influential ways to teach behaviours, attitudes and values (Bandura, 1986). In his social cognitive theory of observational learning, Bandura noted that people could learn certain behaviours through observing models such as parents, coaches and peers. As one pays attention to these models, he argued that observers code the demonstrated behaviours, which they might then use to direct their future learning. Further, he suggested that as people encode the observed behaviour, they consider the relationship between the behaviour and its consequences. An observer is more likely to reproduce an observed behaviour if the model receives positive consequences.

Bandura (1977) also noted that people are more likely to attend to and imitate people who they perceive to be similar to themselves. Indeed, Ste-Marie et al. (2012) highlighted the influence of the model type in observational learning research. There are many different model types and each may provide different information to the learner and influence the success of observational learning for varied reasons, such as impacting on the observer's attention, motivation, and/or other cognitive and behavioural strategies (Bandura, 1977). The following sections will discuss the two most relevant model types for the research presented here: skilled models and unskilled models.

## **Skilled models**

A skilled model is characterized as someone who demonstrates proper execution of the to-be-learned skill with little to no error (Clark & Ste-Marie, 2007; Ste-Marie et al., 2012). Skilled models have prior experience with the task and have also been referred to as expert models (Andrieux & Proteau, 2013; Boyer, Miltenberger, Batsche & Fogel, 2009). It has been shown numerous times that the observation of a skilled model is beneficial for motor skill acquisition (Al-Abood et al., 2001; Bird & Heyes, 2005; Heyes & Foster, 2002). For example, Heyes and Foster (2002) investigated whether observational learning could facilitate the learning of a serial reaction time task. In this particular experiment, participants were divided into three groups: one group observed a skilled model perform 40 trials of the serial reaction time sequence, while another group physically practiced 40 trials of the task, and a control group was included who had no prior information regarding the task. After the acquisition phase participants were tested on their retention and transfer of the serial reaction time sequence. The results indicated that observing a skilled model enhanced the acquisition of sequence information, resulting in the same amount of retention as the physical practice group and better retention than the control. Regarding the transfer test, those in the observation group outperformed those in the physical practice group.

Skilled models are thought to be beneficial for several reasons. Bandura (1977) thought that skilled models helped learners form a standard for error correction; therefore helping them reproduce the learned skill or behaviour accurately. Observing the correct behaviour gives observers a standard against which they can compare their own personal performance (Bandura 1986; Blandin & Proteau, 2000). Another factor that has proven to influence the effectiveness of observational learning is model-viewer similarity. Bandura thought that if the model and the

observer shared common traits, this could enhance the observer's attention and motivation during observation, thus making a peer-skilled model an effective model type (Bandura, 1977; Bandura, 1986). Skilled models are not the only model type that provide benefits to an observer, unskilled models have also proven beneficial to motor learning (Buchanan & Dean, 2010; Lee & White, 1990).

### **Unskilled models**

Unskilled models attempt to perform the desired skill but do so with some degree of error (Ste-Marie et al., 2012). Conventionally, unskilled models have no previous experience with the task and can also be classified as novices. In 1990, Lee and White examined peer-unskilled models while getting participants to learn a computer long jump task. Participants were placed into pairs, wherein one of the participants was to physically practice the task and the other participant observed the physical performance and recorded the scores. Thus, the person learning the task (physical practice group) served as the peer-unskilled model. Afterward, the observer had a chance to perform the same long jump task. The results demonstrated that the participants in the observation group performed just as well as those in the physical practice group. These results were used to show that the observation of a peer-unskilled model is just as beneficial to motor learning as physically practicing the task.

It is thought that unskilled models are beneficial to the learner as it helps them create error detection and correction mechanisms, thereby increasing cognitive and behavioural strategies that enhance their learning (Adams, 1986). Also, it has been shown that the more a model and an observer are alike, the more advantageous it will be to learning (Gould & Weiss, 1981; Meaney et al., 2005). Therefore, as unskilled models are more similar to the observer in terms of skill level, perhaps it increases the effectiveness of observation. Finally, Buchanan and

Dean (2010) hypothesized that unskilled models utilize multiple different strategies in order to complete a skill, providing the observer with a better cognitive representation.

To summarize, unskilled models have been argued to be effective because they provide cognitive and behavioural strategies that result from watching errors in performance; whereas, skilled models are said to enhance learning because they provide a reference of correctness. It has thus been theorized that the combination of different model types (i.e., mixed-modeling) might be the most beneficial for motor skill acquisition (e.g., Baudry, Leroy & Chollet, 2006; Rohbanfard & Proteau, 2011).

### **Mixed-models**

To date, limited research has been conducted regarding the observation of mixed-model types for motor skill acquisition. Baudry, Le Roy and Chollet (2006) conducted one of the first mixed-model experiments, in which participants were learning a gymnastics skill. One group received both expert and self-modeling and received feedback from the coach about the differences between the two models, and the other group received no feedback or modeling video. They found that those in the modeling group had larger improvements in their technique compared to the control group, which is in line with previous observational learning literature. However, as the mixed-model group was compared to a group that received no feedback it is impossible to determine whether the use of mixed-models was better than a single model type.

More recently, Rohbanfard and Proteau (2011) used a knockdown barrier task to determine how the combined observation of expert and learning models might benefit motor learning. In their first experiment, participants were divided into five groups that either (1) observed a learning model (a model that started out unskilled and progressed to being skilled), (2) observed a skilled model, (3) observed mixed-models that combined both the learning and

skilled models, (4) physical practice only, and (5) simply read a magazine (control group with no physical or observational practice). In the first acquisition phase, all participants, except those in the control, either practiced or observed 60 trials of the skill and received knowledge of results (KR) pertaining to the total movement time and the timing of each segment of the task.

Participants in the mixed-model group observed 30 trials with a learning model and 30 trials with a skilled model, where they alternated between watching five trials of the learning model and five trials of the skilled model. After this, all participants completed immediate retention and transfer tests. The second acquisition session included 60 physical practice trials with KR, for all groups, and was followed by a ten-minute and 24-hour retention. It was found that all the observation groups performed better in immediate retention (after the first acquisition session) and immediate transfer than the control. More notably, the mixed-model observation group was found to be just as effective as the 100% physical practice schedule in terms of motor learning, as both groups had no significant differences at the intermediate task timing during immediate retention. Additionally, those in the mixed-model observation group were shown to be better in immediate transfer compared to those in the other two observation groups. Once the participants received physical practice, however, the significant differences between groups disappeared as performances on the 10-minute and 24-hour retention tests were similar. These results indicated that the provision of two model types was in fact more beneficial than a single model alone, and they argued that this may have been because the correct presentation of the skill from the skilled model could be easily contrasted with the performance of the unskilled components of the learning model.

Later, Andrieux and Proteau (2014) wanted to know whether the advantage of mixed-model observation was indeed due to the development of a better error detection and correction

mechanism. Participants were again required to learn a knockdown barrier task with a total movement time requirement of 1,200ms and each phase taking 300ms. The participants were assigned to either a group observing two different learning models, a group observing two different skilled models, a mixed-model observation group (observed one skilled and one learning model) or a control group. In this study, all participants were required to perform a pretest where they physically completed 20 trials of the knockdown barrier task without KR. During acquisition the control group read a newspaper and the observation groups observed a total of 40 trials with KR, 20 trials of one model followed by 20 of the second. Then all the participants were required to do a performance estimation task, a ten-minute retention and a 24-hour retention. The results showed that the mixed model group was better in performance estimation and retention than the two skilled or two learning models. Andrieux and Proteau suggested that these results indicated that mixed-model observation was beneficial due to the varying skill levels of the models being observed and that the observers were better provided with information needed to generate error detection and correction mechanisms.

Returning to consolidation, a notable gap in the observation learning and consolidation literature is the lack of information on the characteristics of the model being observed and consolidation outcomes. As mixed-models have been proven to be more beneficial than a single model type, it would be interesting to investigate whether consolidation is affected differently by mixed-model observation compared to a single model.

### **Mixed-models and consolidation**

Most recently, data has suggested that mixed-models may enhance consolidation processes (Robertson, 2015). In that research, Robertson examined whether mixed-model observation (peer-skilled model and self-observation; i.e., viewing one's just completed

performance on video) was more effective for learning gymnastic skills than self-observation alone. The experiment was a within-subjects design conducted in a gymnastics environment. Each participant learned two gymnastic skills; one where they received a self-observation intervention and the other where they received a mixed-model condition. All athletes completed five testing sessions, with the first session as the pre-test in which participants performed four trials of each to-be-learned skill to determine their baseline ability. The second, third and fourth sessions acted both as retention tests as well as acquisition sessions. Each day athletes began by completing a retention test where they performed four trials of the skill with no video; this was followed by five blocks of acquisition trials where, in each block, athletes watched two trials of the modeling video and then executed two trials of the skill. The fifth session was the final retention test.

While it was found that both modeling conditions promoted learning of the skills, the mixed-models condition was more effective, as their physical performance was significantly better in retention. A second, unexpected, outcome of this research related to consolidation. When comparing the last block of each practice session to the subsequent retention test, it appeared that there was an improvement in performance between sessions despite the fact that there was no further physical practice; i.e., offline learning appeared to emerge (Walker, 2005), which is a basic tenet of consolidation (Trempe et al., 2011).

Although this indicates that consolidation processes might occur after the observation of mixed-models, Robertson's (2015) experiment was not set up to directly examine offline consolidation processes. Therefore, it would be interesting to directly investigate how different model types might affect consolidation processes. Moreover, Robertson's experiment lacked a peer-skilled model only experimental group, thus making it difficult to discern whether the

benefits seen in the mixed-model group were because of the additive benefits of both model types or simply because of the peer-skilled model.

In the current experiment, the use of three experimental groups: a mixed-model observation group (observing both a peer-skilled and peer-unskilled model), peer-skilled model observation group, and peer-unskilled model observation group allowed us to better examine why mixed-model groups may be beneficial to learning. It was decided to use an unskilled model group instead of a self-observation group to avoid a confound faced in Robertson's research. Throughout Robertson's experiment there was no verbal feedback given to the athlete's regarding their performance, therefore the only feedback they were getting was through the video playback. This means that those in the self-observation group obtained feedback on 100 percent of their trials, while those in the mixed-model group only received feedback on 50 percent. Further, if a peer-skilled model group had been included, that group would not have received any feedback regarding their own performance. Due to this, a peer-unskilled model group was used in this experimentation in lieu of a self-observation group.

Consequently, the purpose of this experiment was twofold, wherein the first question had two levels and the second only one:

1a) Is it possible to replicate Rohbanfard and Proteau's (2011) finding that a mixed-model intervention enables better motor learning compared to observing only one model type?

1b) Can we extend the mixed-model advantage with the combination of a peer-unskilled model and peer-skilled model, as compared to Rohbanfard and Proteau's use of a learning model and expert model?

2. Does a mixed-modeling intervention versus a single model intervention affect consolidation processes differentially?

This research is considered significant as it may provide knowledge regarding how different model types affect consolidation, and it will also help discern whether the benefits seen in the mixed-model group from Roberston's experiment were because of the additive benefits of both model types or simply because of the peer-skilled model. The results from this experiment also have practical significance as it can have an impact in any situation in which motor skills are being learned, or relearned. Thus, the aim was to provide coaches, teachers, instructors and rehabilitation specialists with insight into how observation might benefit motor skill consolidation so they can better educate the learners they interact with.

In the following experiment, participants were required to learn a waveform task. Each participant performed a pre-test and an initial acquisition session, followed by 10 minute and 24-hour retention test. When participants returned for the 24-hour retention they also performed a second set of acquisition trials. Seven to eight days after the initial acquisition participants performed a final retention and transfer tests. Based on the results of the aforementioned literature, it was hypothesized that the mixed-model group would show more consolidation and motor learning than those in the peer-unskilled or peer-skilled model groups, thus both replicating and extending the results from Rohbanfard and Proteau (2011).

### **Chapter 3: Method**

## **Participants**

Forty-seven students were recruited from the University of Ottawa (n = 29 female and Mean age of 21.2). A power analysis was conducted to determine the number of participants needed to detect differences between the groups (assumptions: probability (power) 0.8, type one error probability 0.05). 47 participants were tested and two were removed due to missing data, these two participants were replaced at the end with someone in the same condition. Using self-report, all participants were right-handed, had no prior experience with the task, and had no sensory or motor dysfunctions. The experimental protocol received approval from the Research Ethics Board at the University of Ottawa. All participants signed consent forms prior to their participation in the study.

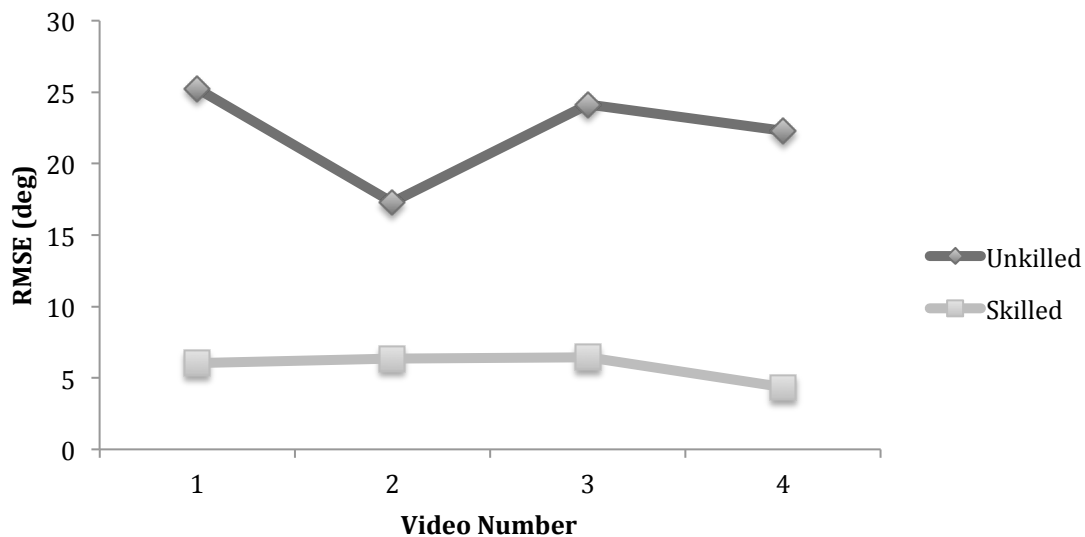
## **Materials**

### *Modeling Videos*

Three different types of modeling videos were used throughout the experiment, specifically, (1) a peer-unskilled model video, (2) a peer-skilled model video, and (3) a mixed-models video (combination of peer-unskilled and peer-skilled model). The peer-skilled and peer-unskilled model videos showed four trials of the respective models' skill level performing the task. Meanwhile the mixed-models video also showed four trials, alternating between a peer-skilled model trial and a peer-unskilled model trial. Therefore, participants in all three conditions had equal amounts of observational practice that was different only in terms of the content. All the observation videos were filmed from the subjective viewpoint, wherein the camera was placed behind the model performing the task (Ste-Marie et al, 2012). The video showed the model's arm performing the task and, once the movement was complete, the angle of the camera

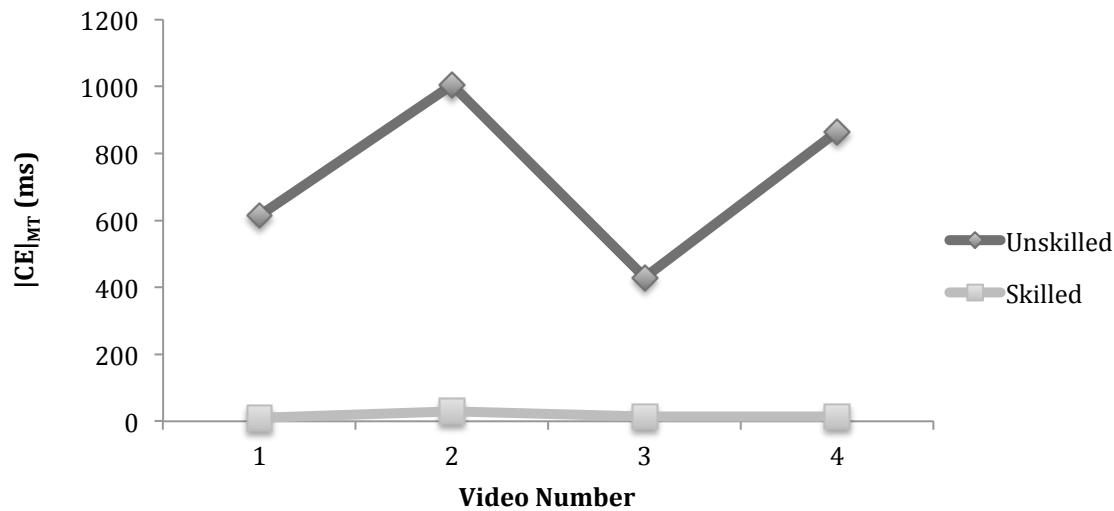
was shifted to display the computer screen that showed the feedback regarding the model's movement.

The skilled model and unskilled model was the same person, who was a peer (i.e., male student of same approximate age as participants). This person was videoed for the first 10 trials of practice with the task. These 10 trials were then analyzed to determine the trials that had the worst root mean square error (RMSE) and the worst movement times, the four worst trials were used to create the unskilled model videos provided during the acquisition phase of the experiment (Figure 4, Figure 5). The person then continued practicing over the time course of several days (performing approximately 150 trials total) and when he was able to execute the task with greater consistency at a near perfect performance, he was videoed again, this time executing 40 trials. From those 40 trials that were videoed, four trials were picked that had the best RMSE and the best movement time. These four trials were used to create the video sequences of the skilled model component.



*Figure 4.* The RMSE of the model in the videos that were watched by the participants. Those in the unskilled group and skilled group observed videos numbers 1 and 2 during the first

observation session in a block and observed videos 3 and 4 in their second observation session in a block. Participants in the mixed-model group observed unskilled video 1 and skilled video 1 during their first observation session and watched unskilled video 2 and skilled video 2 during their second.

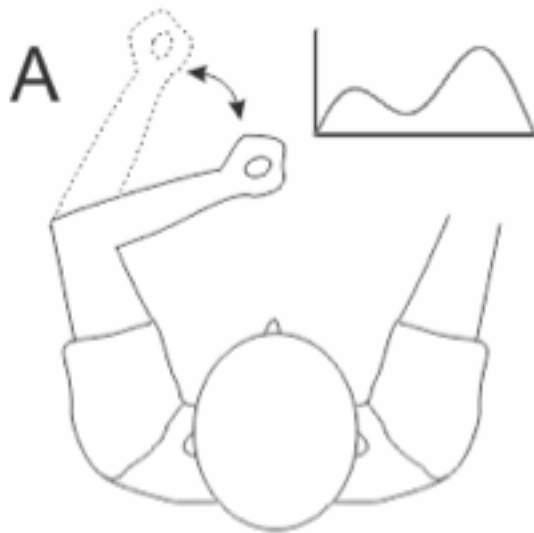


*Figure 5.* The absolute constant movement time error of the model in the videos that were watched by the participants. Those in the unskilled group and skilled groups observed videos numbers 1 and 2 during the first observation session in a block and observed videos 3 and 4 in their second observation session in a block. Participants in the mixed-model group observed unskilled video 1 and skilled video 1 during their first observation session and watched unskilled video 2 and skilled video 2 during their second.

### Task and apparatus

The participants were required to learn a waveform-matching task, wherein they used elbow extension-flexion movements with the non-dominant (left) arm to replicate a waveform as accurately as possible. The waveform was created by summing two sine waves:  $y(t) = 42 \sin(\pi t - 0.3) + 23 \sin(3\pi t + 0.4)$ . The movement had an overall goal time of 900ms.

Participants were seated in a chair facing a computer monitor that displayed the waveform outcome required task, while their left forearm rested on a padded armrest, they grasped a manipulandum attached to an axis restricting movement in the horizontal plane with their left hand. A linear potentiometer, powered by a 5V direct current power supply, was attached to the central axis of the manipulandum to provide position data regarding the arm. The position data was sampled at 1 kHz for all trials using analog-to-digital hardware. A customized LabVIEW (National Instruments Inc.) program was used to control the timing of all experimental stimuli and recorded and stored the data for analysis



*Figure 6.* A visual representation of the required movement and the target waveform

### **Procedure**

All experimental trials took place at the University of Ottawa. Participants were randomly assigned to one of three groups ( $n = 15$  per group): a mixed-models, peer-unskilled model or peer-skilled model group. Prior to the start of data collection, participants were read a set of instructions and observed a PowerPoint presentation regarding the task, the required movement time (900ms) and how feedback on each trial would be given.

### Pre-test

For the pre-test, participants were required to perform ten trials of the waveform task without any feedback. The pre-test served to familiarize the participants with the task, as well as to obtain each participant's baseline skill level. Each trial began with the image of the target waveform displayed on the screen for two seconds, followed by a visual "get ready" cue and an visual "go" cue, in which a light turned green (Figure 7). Given there was no interest in reaction time, the participants were allowed to initiate movement whenever they liked after the "go" cue. During the participant's movement, the computer screen remained blank. Once participants completed their movement the screen remained blank for ten seconds before their next trial. Once the ten pre-test trials were complete the participant began the acquisition phase.

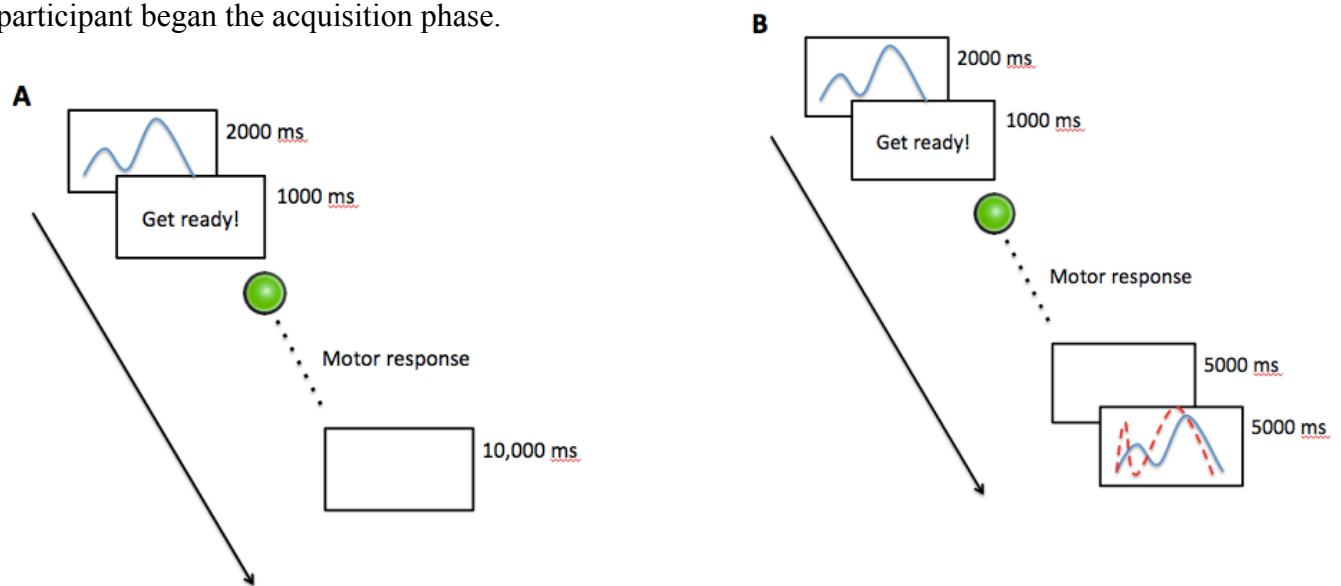


Figure 7. Schematic of the timing of events during the pretest, retention and transfer tests (a) and during a typical acquisition trial (b).

### *Acquisition 1*

During the acquisition trials, participants were required to perform the same waveform task, however, they received feedback after every trial. Participants completed nine blocks of six physical practice trials and four observation trials of the specific modeling video. Within each block, participants performed three physical practice trials and then watched two videos of the required model type, and then performed three more trials and watched two more videos, giving a total of six physical practice trials and four observation trials per block. At the end of each physical practice trial, there was a five-second delay and then feedback was displayed for five seconds comprised of a graphic representation of the participant's movement superimposed on the correct waveform, as well as their movement time (Figure 8). In the observation video trials, the participant saw the model perform the task, and then observed the model's feedback with the same five-second delay followed by five seconds of feedback.

### *Immediate retention*

An immediate retention test was conducted ten minutes after the last acquisition trial. The 10-minute interval allowed participants time to stand up from the chair, get water or go to the bathroom, as needed. The retention test consisted of performing 10 waveform trials without feedback.

### *24-hour retention and Acquisition 2*

Another retention test took place 24 hours following the same procedures as the pre-test session. After the 24-hour retention test, participants performed a second acquisition session following the same procedures as that of the first acquisition session.

### *Weeklong retention/transfer*

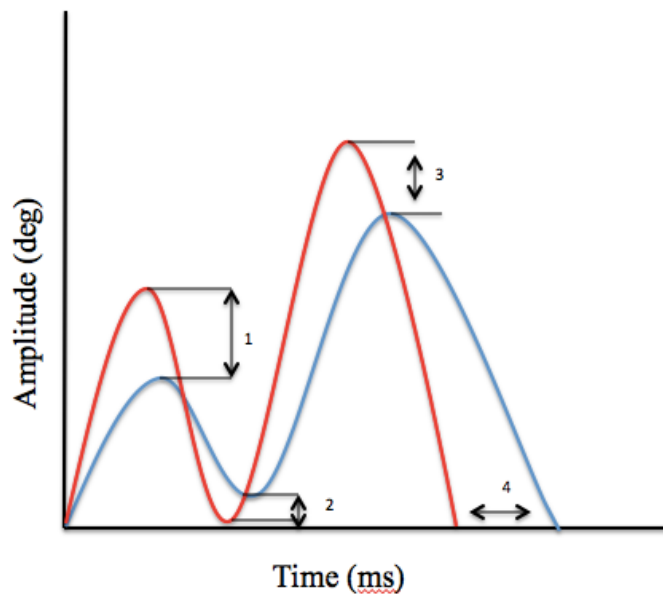
The final retention test was completed seven or eight days following the first acquisition session and followed the same procedures as that of the 24-hour retention and immediate retention tests. There was also a transfer test, which also consisted of ten trials with no feedback of the inverse of the original waveform that had a different goal movement time of 1150ms. The waveform used in the transfer test was the reverse of the waveform participants learned during acquisition. It was important to have a different waveform, as well as a different goal movement time, so that the transfer test encompassed a change in both dependent variables: spatial accuracy and temporal accuracy. Additionally on the last day of testing, participants were required to complete a sleep diary indicating how many hours they slept each night of the past week, this was to ensure that on average participants received the same amount of sleep.

## **Data analysis**

### *Dependent variables*

Three dependent variables were used in the experiment; (1) Root mean square error (RMSE), (2) temporal accuracy for the overall movement time; and spatial accuracy specific to the three reversal points of the movement. RMSE was calculated as the mean difference between the target waveform and the participant's response over the participant's actual movement time. RMSE represents the participants overall performance accuracy per trial and therefore includes spatial and temporal components (Carter & Ste-Marie, 2016). RMSE has been shown to be advantageous for two reasons: not only is it sensitive to spatial and temporal errors in the participant's motor response compared to the target waveform, but also, RMSE incorporates variability and bias of the performed response (Kovacs et al., 2010; Schmidt & Lee, 2011).

The temporal accuracy of the overall movement time was determined by using the absolute constant error ( $|CE|$ ) of the movement time with respect to the goal movement time (Carter, Smith, Carlsen & Ste Marie, 2017; Lin, Fisher, Wu, Ko, Lee & Winstein, 2009). The spatial accuracy was determined by using the sum of the  $|CE|$  in movement amplitude for each reversal point on the waveform (Carter et al, 2016; Lin et al, 2009).



*Figure 8.* Visual representation of the goal waveform compared with a participant's waveform. The blue line represents the target waveform and the red line represents the waveform drawn by a participant. Spatial accuracy was determined by summing the absolute constant error in movement amplitude, demonstrated by numbers 1 through 3 ( $\sum|CE|_{Amp}$ ). Temporal accuracy was calculated by finding the absolute of the movement time difference between the target waveform and the waveform draw, represented by number 4 ( $|CE|_{MT}$ ).

#### *Independent variable*

The independent variable was the video condition, unskilled (UM), skilled (SM) or mixed-model (MM). All the ANOVA's assumptions were verified prior to the analyses. All data

are expressed as means with standard deviations, and  $F$  values are provided for the main effects and interactions. Partial eta squared ( $\eta_p^2$ ) is reported in order to give an estimate of the amount of variance that can be attributed to any significant main effects or interactions. If Mauchly's Test of Sphericity was violated, a Greenhouse-Geisser correction was performed. Statistical significance was set at  $p < .05$ .

## **Chapter 4: Results**

## **Preliminary analyses**

Descriptive statistics were run to explore all the data. Box plots were used to detect any possible outliers and all statistical analyses were run with and without the outliers present. It was determined that there were no changes to any of the significant findings whether or not the outliers were included, therefore the outliers were left in for the analyses. Two participants were not included in the analyses as they had missing data due to the customized LabVIEW program not saving the files properly. Therefore, the data for 45 participants were used for all analyses.

### *Sleep diary analysis*

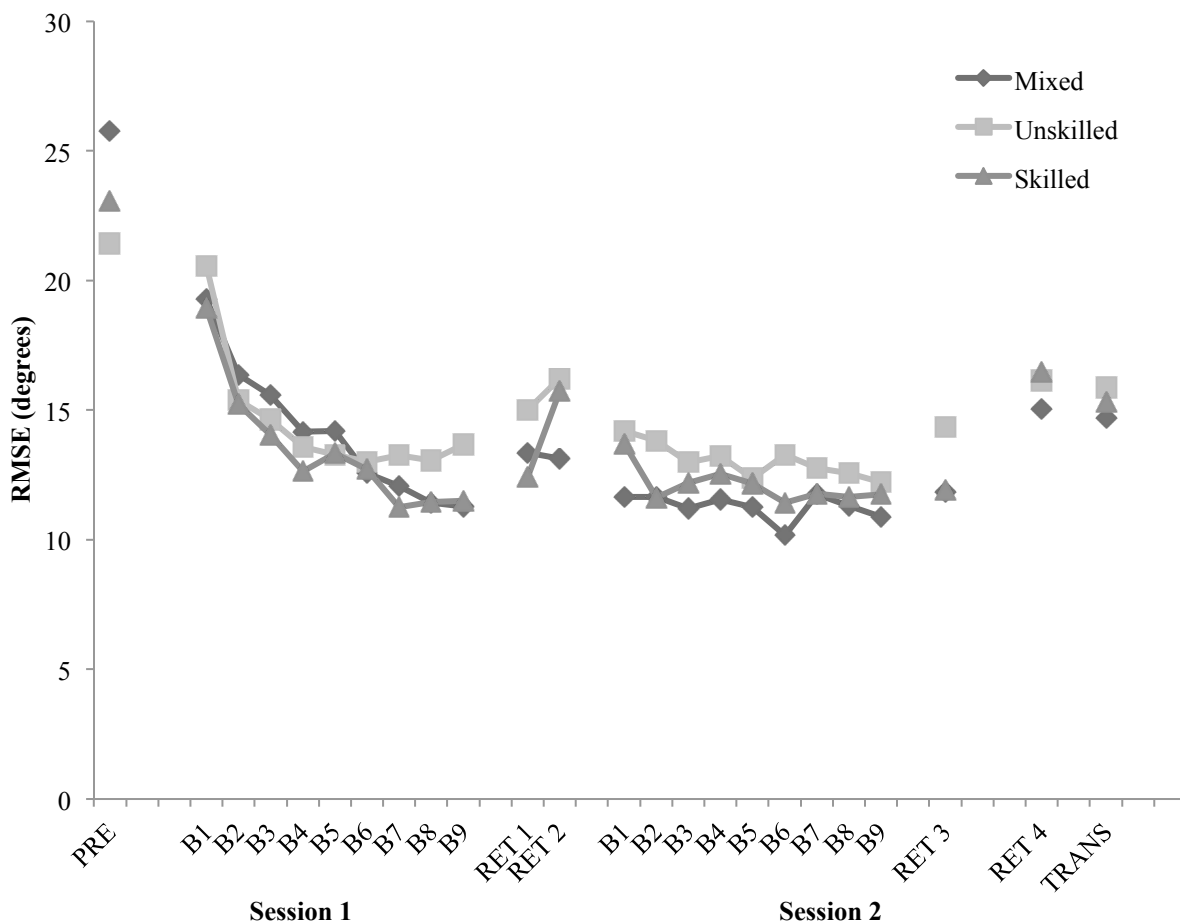
A 3 Video (UM, SM, MM) one-way ANOVA was performed in order to determine if there were any significant differences in the amount of hours of sleep per night between groups. No significant group differences were found ( $p > .05$ ), on average participants slept 7.29 hours per night. The UM group reported a mean of 7.14 hours a night (SD = 0.63), SM reported a mean of 7.43 hours a night (SD = 0.60) and the MM group reported a mean of 7.24 hours a night (SD = 0.69).

A second 3 Video (UM, SM, MM) one-way ANOVA was run investigating the number of hours slept on the night following the first practice session. Again, there were no significant differences found between groups ( $p > .05$ ) and on average participants slept 6.87 hours on the night after Session 1. The UM group reported a mean of 6.47 hours of sleep (SD = 1.36), SM reported a mean of 7.17 hours of sleep (SD = 1.25) and the MM group reported a mean of 6.97 hours of sleep (SD = 1.17).

## **Root Mean Square Error**

*Acquisition.* To examine the acquisition data a 3 Video (UM, SM, MM) x 2 Session (Acquisition 1, acquisition 2) x 9 Block three-way, mixed analysis of variance (ANOVA) with

repeated measures on the last two factors was performed for each dependent variable. RMSE decreased from Session 1 to Session 2 for all the groups which was demonstrated by a significant main effect for Session,  $F(1, 42) = 21.13, p < .000, \eta_p^2 = .335$ . RMSE also decreased across the practice blocks for all groups which was supported by a significant main effect for Block,  $F(4.621, 194.099) = 29.716, p < .000, \eta_p^2 = .414$ . Both these main effects were superseded by an interaction between Session and Block,  $F(4.387, 184.272) = 15.43, p < .000, \eta_p^2 = .269$ . Tukey's HSD post-hoc tests indicated that the interaction was driven by significant differences across certain blocks throughout Session 1, but no such differences occurred in Session 2. The comparisons of interest demonstrated that Blocks 1, 2 and 3 in Session 1 were significantly worse than all blocks in Session 2 ( $p < .05$ ).



*Figure 9.* Average RMSE scores in degrees of each group over the course of the experimental protocol. Where RET 1 is immediate retention 1, RET 2 is 24-hour retention, RET 3 is immediate retention 2 and RET 4 is weeklong retention.

*Retention.* Acquisition scores provide information as to how performance evolves throughout practice, however these might be temporary performance effects, therefore it is important to include retention and transfer tests to investigate the permanence and adaptability of the newly acquired skill (Schmidt & Bjork, 1992). Retention tests allow researchers to examine the relative permanence of the waveform task. Retention data was analyzed with a 3 Video (UM, SM, MM) x 5 Time (pretest, immediate retention 1, 24 hour retention, immediate retention 2, weeklong retention) two-way mixed ANOVA with repeated measures on Time. A significant main effect was found for Time  $F(1.973, 82.864) = 36.285, p < .000, \eta_p^2 = .464$ . Tukey's HSD post-hoc tests indicated that the pretest scores were significantly worse than all the other retention scores ( $p < .05$ ) and weeklong retention was significantly worse when compared to immediate retention 2 ( $p < .05$ ). There were no significant interactions ( $p > .05$ ).

More specific to this experiment, the retention test also provided insight as to whether there were different consolidation processes that occurred for participants within in certain groups (UM, SM, MM). For example, if one group has a large improvement in performance between the immediate retention and the 24-hour retention it would indicate that offline learning, and thus consolidation, occurred. In order to specifically look for this phenomenon a 3 Video (UM, SM, MM) X 2 Time (immediate retention 1, 24 hour retention) two-way mixed ANOVA with repeated measures on Time was performed (Figure 10). There were no significant main effects or interactions found ( $p > .05$ ), although the Video by Time interaction approached significance ( $p = .087$ ). A second 3 Video (UM, SM, MM) X 2 Time (immediate retention 2,

weeklong retention) two-way mixed ANOVA with repeated measures on Time was performed and there were no significant main effects or interactions found.

*Transfer.* The transfer test was included to investigate the adaptability of the newly acquired task, also giving insight into the amount of learning that occurred (Kantak & Winstein, 2011). To investigate the transfer data, a 3 Video (UM, SM, MM) one-way ANOVA was performed. There was no significant main effect ( $p > .05$ ).

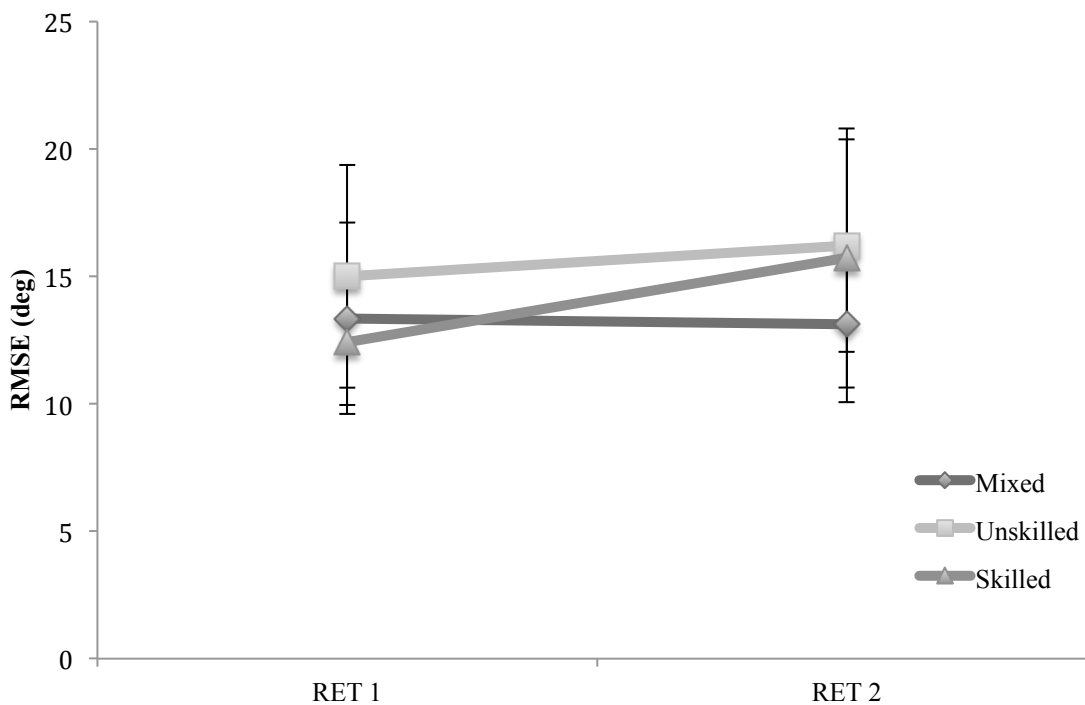


Figure 10. Average RMSE in degrees, of each group at immediate retention 1 (RET1) and the 24-hour retention (RET 2).

### Spatial accuracy

While there were no differences in RMSE, it is possible that there could have been a difference in spatial or temporal accuracy, thus spatial and temporal components of the task were subjected to analysis.

*Acquisition.* A 3 Video (UM, SM, MM) x 2 Session (Acquisition 1, acquisition 2) x 9 Block three-way, mixed ANOVA with repeated measures on the last two factors was performed to analyze the spatial accuracy during acquisition. Similar to the RMSE results, there were significant main effects for Session and Block,  $F(1,41) = 16.822, p < .000, \eta_p^2 = .291$  and  $F(3,116, 129.788) = 17.832, p < .000, \eta_p^2 = .303$ , respectively for spatial accuracy ( $\sum|CE|_{Amp}$ ). As seen with RMSE, these main effects were superseded by a Session by Block interaction,  $F(2,609, 106.973) = 18.432, p < .000, \eta_p^2 = .310$ . Tukey's HSD post-hoc tests indicated that in Session 1, Block 1 was significantly worse than all other Blocks ( $p < .05$ ) and there were no significant differences between any of the other blocks, while in Session 2 there were no significant differences between any blocks ( $p > .05$ ). Performance improvements were seen over the first two blocks of Session 1, but there were no measurable performance differences following these initial blocks, nor in Session 2.

*Retention.* Retention data was analyzed with a 3 Video (UM, SM, MM) x 5 Time (pretest, immediate retention 1, 24 hour retention, immediate retention 2, weeklong retention) two-way mixed ANOVA with repeated measures on Time. As with RMSE a significant main effect was found for Time  $F(1,288, 54.084) = 41.99, p < .000, \eta_p^2 = .500$ . Following a Tukey's HSD post-hoc test it was found that the pretest was significantly worse than all the retention tests ( $p < .05$ ) but there were no significant differences between any of the retention tests. This indicates that all participants were able to improve their spatial accuracy from pretest to immediate retention 1 and that this initial improvement was retained over a week. There were no significant interactions as all the comparisons for mean spatial accuracy ( $\sum|CE|_{Amp}$ ) were not statistically significant ( $p > .05$ ).

As with the RMSE data, a 3 Video (UM, SM, MM) X 2 Time (immediate retention 1, 24 hour retention) two-way mixed ANOVA with repeated measures on Time was performed in order to look for offline learning. There were no significant main effects or interactions ( $p > .05$ ). A second 3Video (UM, SM, MM) X 2 Time (immediate retention 2, weeklong retention) two-way mixed ANOVA with repeated measures on Time was performed to investigate whether there were groups changes over the weeklong retention interval. Again, there was a significant main effect for Time ( $p > .05$ ), which demonstrated that spatial accuracy at the weeklong retention was significantly worse than spatial accuracy at immediate retention 2.

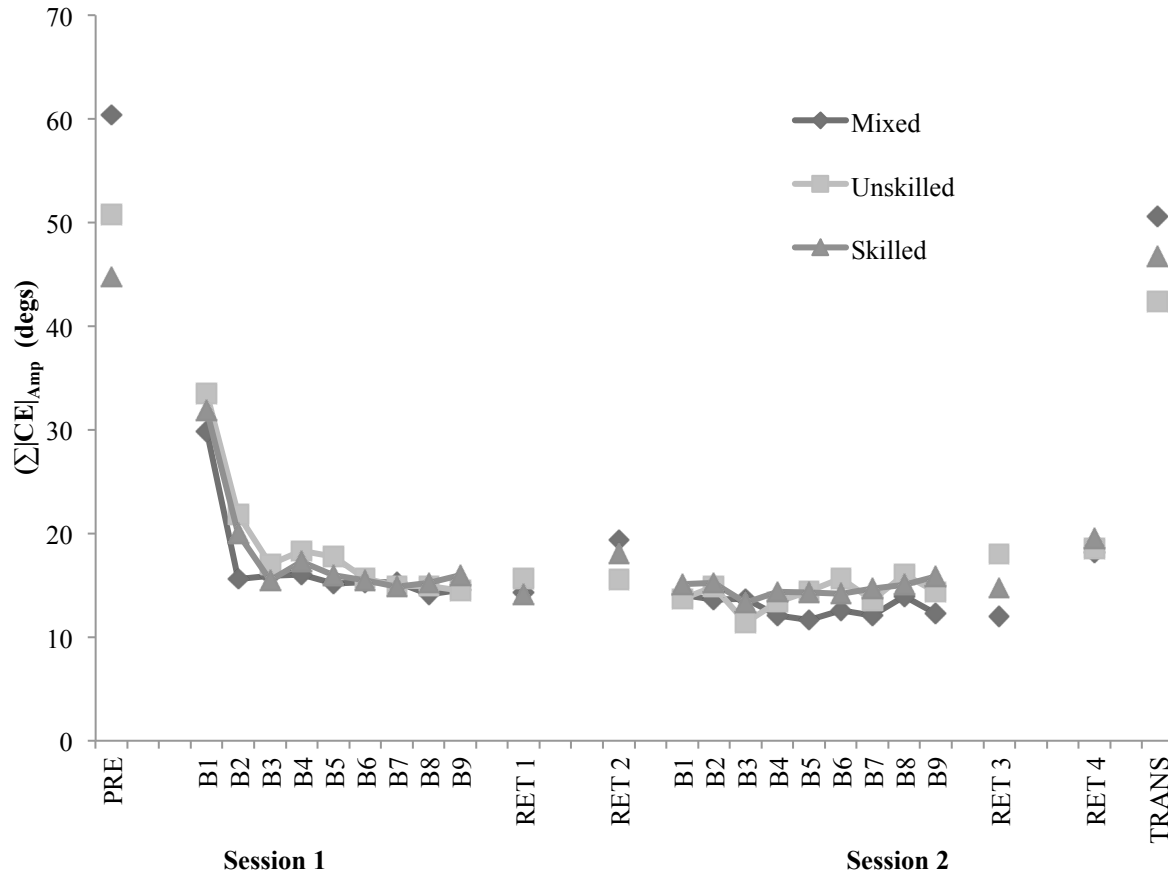


Figure 11. Average spatial accuracy scores ( $\sum |CE|_{Amp}$ ) in degrees of each group over the course of the experimental protocol. Where RET 1 is immediate retention 1, RET 2 is 24-hour retention, RET 3 is immediate retention 2 and RET 4 is weeklong retention.

*Transfer.* To investigate the transfer data, a 3 Video (UM, SM, MM) one-way ANOVA was performed. There was a significant main effect for Video in terms of mean spatial accuracy in transfer,  $F(2,42) = 3.467, p = .040, \eta_p^2 = .142$ . Tukey's post-hoc tests indicated that those in the mixed-model condition were significantly worse in terms of spatial accuracy compared to those in the unskilled model condition. There was no significant difference between the spatial accuracy of those who watched the unskilled model and those who watched the skilled model.

### **Temporal accuracy**

*Acquisition.* A 3 Video (UM, SM, MM) x 2 Session (Acquisition 1, acquisition 2) x 9 Block three-way, mixed ANOVA with repeated measures on the last two factors was also run on the temporal accuracy results. Mirroring the RMSE and spatial accuracy, significant main effects for Session and Block,  $F(1,44) = 23.112, p < .000, \eta_p^2 = .344$  and  $F(1,616, 71.11) = 24.494, p < .000, \eta_p^2 = .358$ , respectively, were found. Again, these main effects were superseded by a significant Session by Block interaction,  $F(1,489, 65.537) = 18.765, p < .000, \eta_p^2 = .299$ . Tukey's HSD post-hoc tests indicated similar findings to the spatial accuracy in that there was a significant improvement from Session 1, Block 1 to Session 1, Block 2 ( $p < .05$ ) and there were no significant differences between any of the other blocks in Session 1 or Session 2 ( $p > .05$ ). Therefore demonstrating there was an improvement in temporal accuracy over Session 1, participants all reached a similar level of performance during Session 1, which was carried over into Session 2.

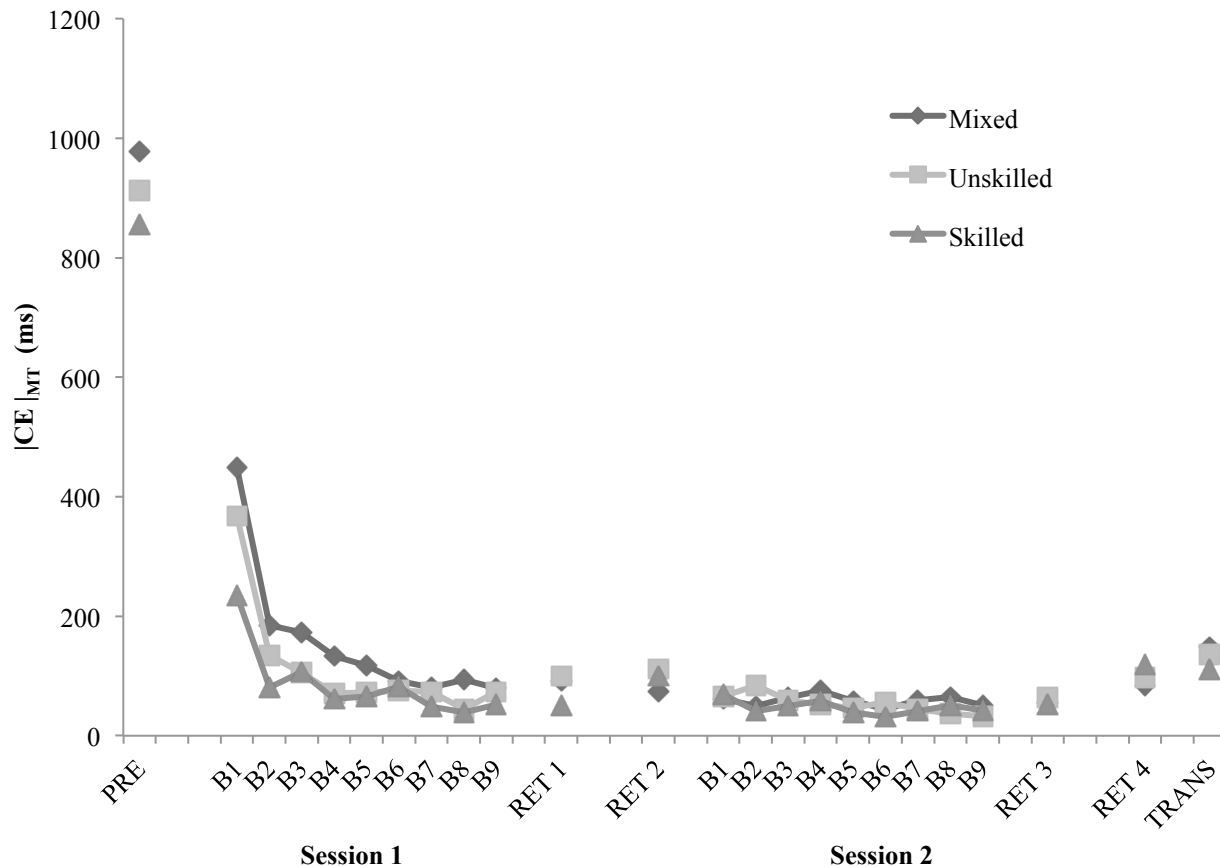
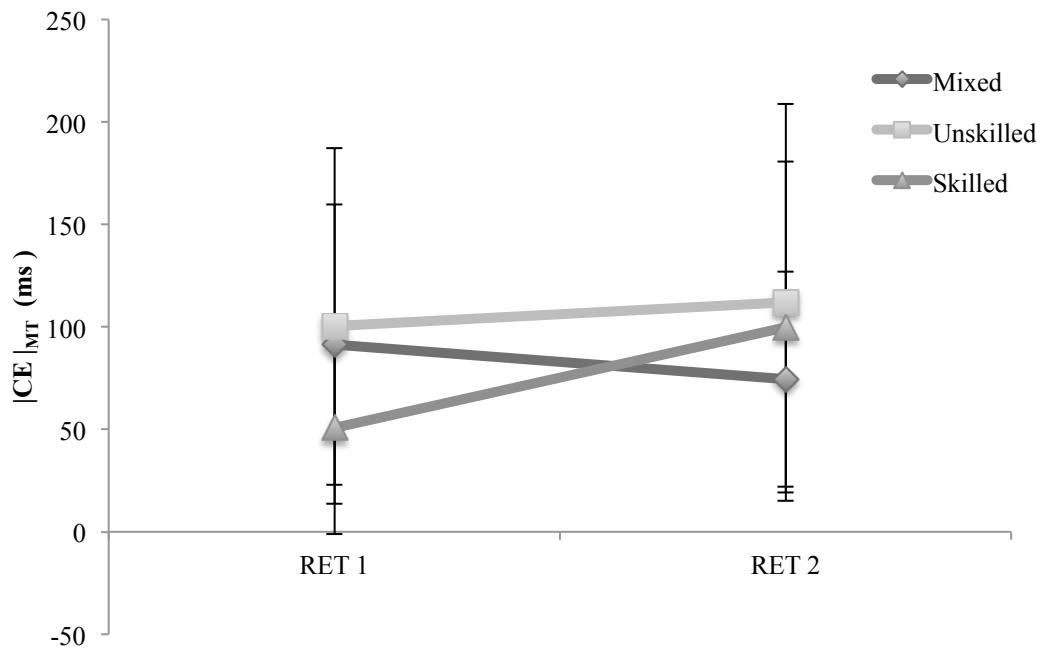


Figure 12. Average temporal error scores ( $|CE|_{MT}$ ) in milliseconds, of each group over the course of the experimental protocol. Where RET 1 is immediate retention 1, RET 2 is 24-hour retention, RET 3 is immediate retention 2 and RET 4 is weeklong retention.

*Retention.* Similar to the two previous dependent variables retention data was analyzed with a (UM, SM, MM) x 5 Time (pretest, immediate retention 1, 24 hour retention, immediate retention 2, weeklong retention) two-way mixed ANOVA with repeated measures on Time. A significant main effect for Time was found,  $F(1.036, 43.516) = 38.603, p < .000, \eta_p^2 = .479$ . A Tukey's HSD post-hoc indicated that the pretest was significantly worse than all the retention tests in terms of mean temporal accuracy ( $p < .05$ ), again demonstrating that temporal accuracy improved quickly and was maintained over the following week. There were no significant

interactions as the comparisons for mean temporal accuracy ( $|CE|_{MT}$ ) were not statistically significant ( $p > .05$ ).

Additionally, a 3 Video (UM, SM, MM) X 2 Time (immediate retention 1, 24 hour retention) two-way mixed ANOVA with repeated measures on Time was performed in order to determine whether offline learning occurred at the 24-hour retention. There was no significant main effect for Time ( $p > .05$ ), however there was a significant Group by Time interaction,  $F(2, 42) = 3.809, p = .030, \eta_p^2 = .154$ . A Tukey's HSD post-hoc showed that the SM group was significantly better than both the MM and UM at the immediate retention. However, as demonstrated in Figure 11, at the 24 hour retention those in the MM group were significantly better in terms of their mean temporal accuracy when compared to both the UM and SM groups ( $p > .05$ ). The Tukey's post-hoc also indicated that the performance of those in the SM group significantly worsened over the 24-hour retention, while those in the US and MM observation did not show significant changes in performance.



*Figure 13.* Average temporal error scores ( $|CE|_{MT}$ ) in milliseconds, of each group at immediate retention 1 (RET1) and the 24-hour retention (RET 2).

Another 3 Video (UM, SM, MM) X 2 Time (immediate retention 2, weeklong retention) two-way mixed ANOVA with repeated measures on Time was done to investigate whether offline learning also occurred over the weeklong retention. A significant main effect for Time ( $p > .05$ ) was found; demonstrating that performance during immediate retention 2 was significantly better than at the weeklong retention. There was no significant Group by Time interaction.

*Transfer.* A 3 Video (UM, SM, MM) one-way ANOVA showed no significant main effects ( $p > .05$ ).

## **Chapter 5: Discussion**

There are many different factors that affect how proficiently one learns a novel motor skill. One way that motor learning can be enhanced is through observation of a model performing the motor skill to be learned (Ste-Marie et al, 2012). Previous research has indicated that there are several model characteristics, such as skill level, that can influence the effectiveness of observation (Meany et al., 2005). Skilled models and unskilled models have both proven to be beneficial to motor learning; however, it is thought that they both provide different information to the observer (Rohbanfard & Proteau, 2011). Therefore, more recently, mixed-modeling, or the observation of two different model types, has become of interest to motor learning researchers and several experiments have found mixed-modeling to be superior to a single model alone. Further, it has been argued that the mixed-model may be beneficial due to additive benefits of the different model types (Rohbanfard & Proteau, 2011; Roberston, 2015).

Thus, the first objective of this experiment was to determine if we could replicate the advantages of mixed-model observation over a single model type alone through the use of a mixed-model group, a skilled model group and an unskilled model group. Based on past research that has favoured mixed-modeling (Rohbanfard & Proteau, 2011) it was posited that those in the mixed-model group would show reduced error scores and thus, better motor learning, compared to those who observed a peer-skilled or a peer-unskilled model alone. An important second objective was to determine whether the observation of a mixed-model compared to a single model would affect consolidation processes differently. It was hypothesized that those in the mixed-model group would also show more consolidation compared to those in the single model observation groups.

To turn to the first objective, the acquisition findings showed that all three dependent variables (RMSE, spatial accuracy and temporal accuracy) had main effects for Session and

Block, which were superseded by a significant Session by Block interaction. This interaction revealed that participants demonstrated worse performance in the initial blocks of Session 1 as compared to Session 2, but the later blocks of Session 1 and Session 2 were not different from each other. Thus, performance improvements largely occurred in the first four blocks of Session 1 and then performance improvements were not attained thereafter. This rapid improvement indicates that all participants acquired the task quickly and that the interspersing of physical practice and observation allowed for fast improvements in motor performance.

The greater interest, however, was whether the observation of a mixed-model led to differential physical performance over practice. Although those in the mixed-model group appeared to have the best RMSE and spatial accuracy scores over both acquisition sessions, these differences were not significant for any of the dependent variables. Thus, the results from this experiment suggest that all the practice conditions were beneficial to performance during acquisition, but no one condition was significantly better than the others.

The fact there were no differences in acquisition is not that problematic given that the retention scores provide more insight into the impact of the video modeling conditions on motor learning than do acquisition scores. In retention, a significant main effect for Time was found for all three dependent variables. The post hoc analyses showed that the pre-test scores for all groups were significantly worse than all the following retention scores. These findings indicate that, by the end of the first acquisition session, all participants had learned the skill to the same degree, regardless of the video modeling condition provided. These results also suggest that this newly acquired skill level did not change significantly following the second acquisition session, or even a week later, therefore indicating that the learning was permanent. One exception to this finding occurred with RMSE in which the weeklong retention results were significantly worse than the

immediate retention 2 scores. Thus, RMSE was not retained as well over a week, although it still remained significantly better than the pretest scores and was not significantly different from immediate retention 1 or the 24-hour retention. Taken together these results indicate that the waveform-matching task was learned and this learning was retained following 24 hours and a one-week time frame.

Our specific interest in consolidation processes was examined through the 3 Video (UM, SM, MM) X 2 Time (immediate retention 1, 24 hour retention) two-way mixed ANOVA with repeated measures on Time. While there were no significant differences found for spatial accuracy, significance was found for temporal accuracy, and the results for RMSE had a strong trend in the same direction that approached significance. That is, those in the skilled model observation group were significantly better at immediate retention 1; however, this result is not of interest. Immediate retention was included simply to have participants perform the skill with the same parameters as they would at the 24-hour retention, so as we could directly compare these two time points and determine whether offline learning occurred. The delayed retention has been found to be a more reflective measure of the permanence or learning of a skilled compared to an immediate retention test (Kantak & Winstein, 2012). Thus, more importantly, performance of those in the mixed-model observation group was significantly better at the 24-hour retention compared to the other two groups, suggesting the mixed-model condition enables one to be more resistant to forgetting.

As the 24-hour interval did not lead to performance decay this suggests that changes occurred in the central nervous system so that the new memory was stored over the longer-term, and this could perhaps be deemed performance stabilization (Trempe et al., 2011), however, as we did not specifically look for the phenomenon we will not call this phenomena performance

stabilization. These findings support the conclusion that mixed-model observation leads to better retention over the 24-hour timeframe, and this cannot be fully explained by consolidation processes. At the weeklong retention, those in the mixed-model group no longer demonstrated this better retention and there were no significant differences between groups. Therefore, it appears that there is a mixed-model benefit that arises early in learning but this benefit diminishes following larger amounts of practice.

Before moving to discuss the transfer results it is important to speak to potential reasons why the mixed-model benefit was only demonstrated in terms of temporal accuracy and not RMSE or spatial accuracy. This finding is in line with much of the previous research done concerning mixed-models, as there are rarely dependent variables related to spatial accuracy, and thus most mixed model benefits have been shown only in terms of timing variables (Rohbanfard & Proteau, 2011; Andrieux & Proteau, 2013; Andrieux & Proteau, 2014). Additionally, typical consolidation research uses tasks such as serial reaction time tasks and sequence production tasks with dependent variables mostly related to timing, such as, mean total execution time and relative timing. Thus, most significant results have been demonstrated through timing variables (Borrogan et al., 2015; Malangré et al., 2014; Trempe et al., 2011). Some consolidation research has used finger tapping tasks, which often use accuracy as a dependent variable which could be considered as capturing spatial accuracy, however, these tasks differ greatly from ours. Namely, participants have an obvious goal and receive immediate feedback as to when that goal was met, whereas in our experiment participants did not receive feedback until the entire movement was complete. Other consolidation research has used motor adaptation tasks, which have dependent variables such as angular error, a form of spatial accuracy (Hill et al., 2008; Trempe, 2012). Motor adaptation tasks which require the individual to adjust a parameter of an existing

movement pattern, however, are quite different from the task used in this experiment which required the learning of a new movement pattern that had temporal and spatial constraints. Therefore, it is possible that there was no mixed-model benefit in spatial accuracy due to the differences in the motor movement being learned.

Transfer was assessed once, seven to eight days following Session 1 in order to examine the impact of the modeling conditions on the adaptability of the motor skill, yet another learning characteristic (Schmidt & Bjork, 1992). Transfer was only assessed at one time point during the experiment as we did not want the participants to begin to learn the transfer skill and we did not want the transfer skill to potentially interfere with the consolidation of the original waveform. For both RMSE and temporal accuracy there were no significant differences between Video conditions; therefore indicating that learning between all groups was the same. Spatial accuracy, however, showed a significant main effect in terms of Video, but this difference was not in the expected direction. Specifically, there was no significant difference between those in the skilled and unskilled observation groups, however those in the mixed-model group were significantly worse compared to the unskilled observation group. This result came as a surprise and is difficult to explain. This result could perhaps be explained by the fact that those in the mixed-model observation group had more difficulty breaking away from the spatial component of the task that they had already learned. This speculation is supported by the fact that during immediate retention 2 those in the mixed-model observation group had the best spatial accuracy (12.02, SD = 6.34), while those in the novice model observation group had the worst (17.99, SD = 9.88), although these results are not significant it would nonetheless contribute to a possible reason why those in the novice model observation group were better during transfer.

Additionally, a 3 Video by 2 Time two-way mixed ANOVA with repeated measures on the last factor was run to examine the differences between the pretest results and the transfer results. The ANOVA indicated spatial accuracy was not significantly different between pretest and transfer ( $p = .341$ ). This suggests that the performance at the time of the transfer test was no different than when the participants started to learn the task, so one can question whether there was really any transfer occurring at all. As such, while the spatial accuracy data showed the unskilled model was best at performing the spatial component of the task, we are cautious with the interpretation that this outcome was driven by the intervention itself.

Although our results do replicate the mixed-model advantage found by Rohbanfard and Proteau (2011), there are nonetheless some key differences in terms of their results that can be explained by differences in experimental design. Rohbanfard and Proteau used a different schedule of physical practice and observation. In their experiment, participants in the observation groups first observed 60 trials of their specific model type performing the task; this was followed by what they called an immediate-retention test. After that test, all participants received 60 physical practice trials, which were followed by 10-minute and 24-hour retention tests. This is notably different from our experiment wherein physical and observational practice were interspersed throughout acquisition. Rohbanfard and Proteau only found significant differences in RMSE between groups on the immediate retention test, which is assumed to have occurred immediately after the practice session.<sup>1</sup> Specifically, those in the mixed-model observation group did not differ significantly compared to those who physically practiced the task for the first 60 trials, whereas the novice or expert observation only groups performed significantly worse. Once the participants received physical practice, however, the significant differences between groups

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<sup>1</sup> The time interval between practice and immediate retention was not provided in the manuscript.

disappeared as performances on the 10-minute and 24-hour retention tests were similar. This is different from our results which showed those in the skilled model observation group were significantly better than the skilled and mixed-model observation groups at the immediate retention, while at the 24-hour retention test the mixed-model observation group was the significantly better than the other two. Therefore, it seems that when observation and physical practice are interspersed within an acquisition session the mixed-model advantage takes longer to emerge than when observation and physical practice occur separately.

This speculation is supported by results from Andrieux and Proteau (2013), which included two experiments. In both experiments, they used the same knockdown barrier task as Rohbanfard and Proteau (2011) and had three experimental groups: a learning model observation group, an expert observation and a mixed-model observation group. In the first experiment, all groups simply observed 60 trials of the task, which was followed by 10 minute at 24-hour retention tests. At the 10-minute retention test the mixed-model observation group performed significantly better than the skilled and unskilled observation groups, however these differences were no longer significant at the 24-hour retention. In experiment 2, all groups received interspersing of physical practice and observation, where 10 observation trials were followed by 10 physical practice trials until a total of 60 trials were reached. Following practice, they also had participants perform a 10-minute and 24-hour retention tests. The results from the 10-minute retention test showed no significant differences between the observation groups. At the 24-hour retention, Andrieux and Proteau found no significant differences between groups in terms of the absolute constant movement time error, however, they did show that those in the mixed-model and expert observation groups were significantly better than those in the novice observation group in terms of relative timing error. Thus, our evidence, and that of Andrieux and Proteau

(2013), strongly suggests interspersing physical and observational practice may differentially impact the learning effects of different model-types as compared to the sequential use of both practice types, in that the mixed-model advantage is more pronounced at the 24-hour retention.

A similar mixed-model advantage was also reported by Roberston (2015). The results showed that when physical practice and observation are interspersed, a mixed-model observation intervention (expert model and self-as-model) was more beneficial in the learning of a gymnastics skill than self-observation alone (i.e., observing one's most recent performance on video). This advantage was not seen until the participant's second retention test and it was also seen at the post-test. Due to the experiment following a typical gymnast's training schedule the exact length of the retention interval is unclear, however, it is certain that it was at least 48 hours and perhaps even closer to a week. This means that the mixed-model advantage was retained over period of time longer than 24 hours. This is evidently different from the results of the current experiment wherein the learning advantage was seen at 24-hours, but not retained over a longer period of time (at the weeklong retention). In Robertson's experiment, the alternate model type was a self-model, as opposed to the unskilled model used here; consequently, when participants only observed themselves as the model, they were receiving feedback on every trial as to how they performed the skill. Conversely when learning under the mixed-model condition they observed one self-observation trial and one expert demonstration, thus only receiving performance feedback 50% of the time. It is possible that this difference in feedback frequency (100% vs 50%), coupled with the modeling differences is a factor to consider. That is, in the current experiment and other relevant experiments (Andrieux & Proteau, 2013; Rohbanfard & Proteau, 2011), participants, regardless of their model-type, also received feedback on 100 percent of their trials. This leads us to the possibility that when physical and observational

practice is interspersed *and* participants receive less feedback, it could lead to a mixed-model advantage that is retained over a longer period of time.

Certainly, the augmented feedback literature has spoken to the potential detriments of 100% feedback schedules. Then, perhaps when participants get 100 percent feedback there is not enough cognitive demand for the task, and this is why the mixed-model benefit was not retained in the longterm. The aforementioned idea regarding cognitive effort was brought forth by Lee, Swinnen and Serrien (1994) when they proposed that cognitive effort is an important factor in motor learning and if cognitive effort is increased, learning will increase as well. It is thought that when feedback is given too often, learners will become too reliant on this feedback and will be unable to interpret intrinsic feedback on their own (Lee et al., 1994). Thus, it can be argued that Robertson (2015) reported a long lasting mixed-model advantage due to the increased cognitive effort employed by the learners as they received less overall feedback. Thus, the current experiment succeeded corroborating previous research findings in that a mixed-model intervention enables better motor learning compared to observing a single model type alone, although this mixed-model benefit was seen only at the 24hr retention test.

It is also important to speak to the second objective of the research; that is, to determine whether there are differential consolidation outcomes as a result of observing different model types. Robertson (2015) proposed that the mixed-model learning superiority in her experiment might have occurred due to enhanced consolidation processes. Indeed, it has been suggested that consolidation can occur following observation, but the distinct behavioural outcomes of consolidation are slightly different than those that appear following physical practice (Trempe et al., 2011).

In the current experiment we did not see typical behavioural outcomes of consolidation, however we did find significant differences in retention between the different observation groups. Although there were improvements between the immediate retention test and the 24-hour retention test for the mixed-model group, we did not show offline learning. If we had seen typical behavioral outcomes of consolidation, there would have been significant improvements between the immediate retention tests and the 24-hour or week-long retention tests, showing offline learning. We hypothesized that those in the mixed-model group would have demonstrated offline learning, these would have been similar results to what Robertson (2015) found when the mixed-model group showed indications of offline learning after the third acquisition session. There are multiple differences between our research and Robertson's research that could account for the fact that we did not see offline learning or any differences in consolidation between groups. One potential reason is due to the fact that the participants in Robertson's experiment had less overall practice and longer times to consolidate across each practice session. For example, the gymnasts in that experiment received a total of 80 trials (combining both the observational and physical practice trials in acquisition and retention) over 5 sessions that spanned two weeks, whereas in our experiment participants were provided 230 trials over two acquisition sessions that spanned two days of practice. Thus, it is possible that the distributed practice with more time between practice sessions led to the differing results.

Furthermore, the larger amount of practice allowed in the current experiment could have caused the participants to become too proficient at the skill, thus not allowing for consolidation to be seen. Trempe et al. (2012) found that no offline learning occurred if participants reached a certain skill level by the end of acquisition. Therefore, it is possible that all our participants reached this specific skill level by the end of their first acquisition session, as shown by their

unchanging error scores in figures 9, 10 and 11. If participants reached this performance ceiling, offline learning does not have the potential to emerge, as they would be unable to significantly improve their performance no matter how much more practice was allowed. Therefore, we suggest that one of the potential reasons we did not see offline learning was due to the fact that there were too many acquisition trials and by the end of the first acquisition session participants had already reached their performance ceiling.

To our knowledge, there have only been three experiments that investigated observational learning and consolidation together, and none have focused on how different model types might affect the amount of consolidation that occurs. Trempe and colleagues (2011) concluded that the behavioural outcomes of consolidation following observation are not the same as those following physical practice. This was evident in the fact that following observation there was no evidence of offline learning. Trempe and colleagues still concluded that because there was no performance decay it suggests that changes still occurred in the central nervous system (Trempe et al., 2011). In our experiment, as there were no significant differences between any of the retention tests, no matter the dependent variable, it suggests that there was also no performance decay, and albeit, no offline learning. As the interspersing of physical practice and observation has never been done before when looking specifically at consolidation, it is possible that the observation of any model type overrules the offline learning effects that would be seen during physical practice alone and this is why we did not see typical offline learning, similar to Trempe et al's findings (2011). Therefore, consolidation appears to have occurred similarly across the observation of all model types, as there were no significant differences between groups.

## **Limitations and delimitations**

As with all research there were some delimitations and limitations within the experimental design. A delimitation is purposely implemented in the experimental design in order to limit the scope and define the boundaries of an experiment, while limitations are potential weakness of the experiment that are not within the experimenter's control (Simon, 2011). One limitation of the current experiment was that it was difficult to ensure that all the participants paid attention to the modeling videos. It is possible that some participants were more attentive than others, therefore potentially causing discrepancies in the amount of practice obtained by each participant.

The first delimitation that came to light was the lack of variation in the model videos watched by the participants because the same four videos were repeatedly shown throughout acquisition trials. A second delimitation was that the choice of the waveform-matching task that participants were required to learn; this task has never been used in consolidation research and the rapid learning of the task may have had an impact on the results. Another delimitation is related to the groups chosen in the current experiment, in which there were the three main groups of an unskilled model, skilled model, and mixed-model who all obtained physical and observational practice. For a more direct comparison with Rohbanfard and Proteau's (2011) design, we would need to add a physical practice only group and a control group who received no physical practice or observation.

## **Future Research**

As there were several delimitations regarding the current experiment, there are several areas for possible growth in the area of observational learning and consolidation. For example, it would be worthwhile to investigate the ideal amount of variation within videos provided to the

observer in order to determine whether the number of different videos of a specific model type can affect the amount of motor learning that occurs. Another area of future research would be to include physical practice only, observation only and control groups to the current experiment. This would be beneficial in giving more insight as to how the interspersing of physical practice and observation compares to physical practice alone in terms of consolidation and motor learning.

Several speculative explanations of the current results were considered in the discussion, all of them leading to potential areas of future research. The first regarded the amount of feedback provided when observation and physical practice are interspersed, as mentioned earlier it is possible Robertson (2015) saw the mixed-model advantage retained over longer periods of time due to the fact that participants in the MM group received less feedback. It was also mentioned that the addition of physical practice only and observation only groups would be beneficial, as it would allow us to determine whether consolidation can occur when participants learn a waveform-matching task and whether the results we obtained were due to the task or due to the observation component. It is possible that we did not see typical behavioural outcomes of consolidation due to the task we used or due to the observation; however, it is impossible to know without additional groups.

## **Conclusions and Implications**

The results from this experiment suggest that when participants learn a waveform-matching task under practice conditions that intersperse observation and physical practice that observing a skilled model is most beneficial for performance, but mixed-model observation is most beneficial for learning. Nonetheless all participants were able to learn the novel motor skill and the skill was relatively well maintained over the week following acquisition, indicating little

performance deterioration. More importantly it was found that temporal accuracy of those in the mixed-model observation group was significantly better than unskilled model or skilled model observation at the 24-hour retention, however, this mixed-model benefit was not retained over the long-term. The finding of a mixed-model benefit solely at the 24-hour indicates that the observation of a mixed-model is advantageous when individuals are acquiring the task but not for skill refinement. This could be framed in terms of Gentile's two-stage model of learning. Gentile proposed that in the initial stage of learning a learner is simply getting the idea of the movement, while in the later stage the learner begins to fine-tune the movement (Gentile, 1972). Perhaps, then, observing a mixed-model is most beneficial when learners are in this early stage of learning as it helps them understand the movement.

It is hoped that when research in this area continues to progress and provide more robust results that this information will have practical implications in sport and rehabilitation. If coaches, teachers and rehabilitation specialists know that mixed-model observation is most beneficial in early learning, it will enable them to provide the best possible practice conditions to optimize motor skill acquisition.

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