Annual Review of Cybertherapy and Telemedicine
Volume 4 Year 2006 ISSN: 1554-8716

Virtual Healing: Designing Reality

Editors:
Brenda K. Wiederhold, PhD, MBA, BCIA
Stéphane Bouchard, PhD
Giuseppe Riva, PhD, MS, MA
Implicit Learning of an Embedded Regularity in Older Adults using a SRT Reaching Task in a Virtual Reality Medium

R. Martini¹, L. Aquilino¹, S. Buissé¹, A. Dumais¹, V. Pion¹, E. St. Rose², H. Sveistrup¹, & D. M. Ste-Marie²

¹ Occupational Therapy Program, School of Rehabilitation Sciences, Faculty of Health Sciences, University of Ottawa
² School of Human Kinetics, Faculty of Health Sciences, University of Ottawa

INTRODUCTION

Motor learning in rehabilitation can be facilitated by different forms of knowledge (Strangman, Heindel, Anderson, & Sutton (2005). To do so appropriately, it is important to understand how different tasks may facilitate or inhibit these different forms of knowledge. Learning any task involves at least two forms of learning: explicit and implicit. Explicit learning is characterized as learning within conscious awareness and is under intentional or voluntary control of the performer (Gentile, 2001). In contrast, implicit learning is described as operating outside one's conscious awareness and is under automatic control of the performer (Gentile, 2001). In general, declarative and metacognitive processes are the equivalent of explicit knowledge. Procedural knowledge, on the other hand, relates more strongly to implicit knowledge (Dienes & Perner, 2002). Traditional theories of motor learning generally propose that the earliest phase of motor skill acquisition is acquired explicitly and, as learning progresses, skill performance becomes more implicit (Gentile, 2001; Maxwell, Masters, Kerr, & Weedon, 2001). Recent research has challenged this assumption (Maxwell et al., 2001). Evidence suggests that many skills are learned without ever encoding verbal rules or acquiring conscious knowledge regarding underlying rules or regularities (Goschke, 1998). More recently, researchers have argued that initial representations acquired during learning can take either explicit or implicit forms, and with practice, each can be transfigured from one form to the other (Maybery, Taylor, & O'Brien-Malone, 1995; Park & Shea, 2005).

Past investigations of implicit and explicit learning have focused on two different issues: the learning of a specific task and the learning of embedded regularities (i.e., a regularly occurring predictive pattern), and our research focus was on the latter. The ability to note recurrent regularity in the physical or social environment is necessary to be able to adapt to a changing world. Researchers exploring the learning of regularities have investigated whether implicit learning of an embedded regularity can occur. Traditionally, serial response time (SRT) tasks have been employed that require a finger key press in response to a visual stimulus (Goschke, 1998). A predictive sequence (regularity) is embedded throughout the visual stimuli presentations and the standard result is that the response times for the embedded pattern are faster than for random sequences, despite the participants not demonstrating conscious awareness of that regularity (Meulemans, Van der Linden, & Perruchet, 1998).

In the literature, age has been shown to affect the acquisition of tasks requiring conscious processing; whereas tasks that can be learned without conscious awareness are not influenced by the effects of age (Durkin, Prescott, Furchtgott, Cantor, & Powell, 1995; Willingham, 1998). The SRT task is said to have a motor component (Goschke, 1998; Willingham, 1999). It is well known that older subjects demonstrate slower motor responses (Willingham, 1998). Regardless of this motor slowness, similar degrees of implicit learning of a simple, or low, order SRT repeated pattern by both older and younger adults have been shown, with older adults performing more poorly on a test of explicit knowledge of the repeated sequence (Howard & Howard, 1989; Howard & Howard, 1992). However, when using sequences that required more complex or higher-order learning, older adults were able to implicitly learn some second order associations, but demon-
strated poorer implicit learning of more complex sequences (Curran, 1997; Howard & Howard, 1997; Howard, Dennis, Yankovich, & Vaidya, 2004). In their study of spatial and spatiotemporal context learning, Howard et al. (2004) found dissociation between older and younger adults using a higher order visuospatial sequence (i.e., an alternating structure serial reaction time-ASRT) task, but such dissociation was not found for their contextual cuing task that did not entail motor sequencing. So they proposed that differences found in the ASRT task may be attributed to age-related impairments in motor sequencing and that these deficits only become apparent when higher order sequences are used.

The SRT tasks used in these earlier studies, however, employed similar simple movement response that is not reflective of the kind of complex processing required for most daily activities. This is a serious limitation of the previous research in this field. Indeed, Wulf and Shea (2002) claim that findings from studies that use simple skills do not readily transfer to the learning of more complex skills. Thus, to understand different forms of learning processes, more complex skills need to be used in motor learning research. For some tasks, complexity can be influenced by factors such as movement time or degrees of freedom (Wulf & Shea, 2002). The present study used a dynamic, whole body movement task that required both spatial and temporal precision demands. Specifically a gross motor reaching task was used in a virtual reality environment. For this study, SRT will refer to serial response time, as in Willingham (1999), as this was the actual measure obtained during the reaching task.

The purpose of the present study was to determine whether older adults learn an embedded regularity in a gross motor serial response time (SRT) reaching task in a virtual reality environment. In addition, we hoped to determine whether they learned the pattern implicitly and/or explicitly.

**METHOD**

**Participants**

Ten female and seven male (n = 17) healthy older adults recruited from local community centers in the Ottawa region served as participants. The participants had a mean age of 68.8 years (range = 63-80 years). Participants were excluded if they presented with any of the following self-reported conditions: physical limitations in upper extremity range of motion, balance problems, or poor standing tolerance. Due to technical difficulties with the virtual reality system, the data from six of the participants were dropped, leaving the data of 11 participants for analysis.

**Experimental task**

A novel virtual reality (VR) SRT task was used. A digital camera captured the participants’ image in real-time allowing the participants to see themselves on a television monitor within the virtual environment. A tripod was placed in front of each participant at the level of the home position as a consistent point of reference for initiation of movement. Participants placed their preferred hand on the tripod and reached out to contact balls as quickly as possible as they appeared at one of the four quadrants of the screen. They returned their hand to the home position (response) after each reach as this activated the appearance of the next ball (stimulus). The response-stimulus interval was set at 0ms as it was demonstrated that such an interval facilitates implicit learning (Destrebecqz & Cleeremans, 2001). The time that it took for participants to move their hand from the tripod to each of the blue balls (response time) was recorded by the system.

Studies that have used an SRT task to determine implicit learning of a repeated pattern used a high number of trials. For example, Shanks, Rowland and Ranger (2005) used 100 trials over nine blocks and Destrebecqz and Cleeremans (2001) used 96 trials over 15 blocks. The present study employed a task requiring gross motor movement that is more susceptible to fatigue than a simple motor task such as key presses. A high number of trials would have therefore been excessively tiring and may have affected ability to detect learning. Thus, for the SRT task during the acquisition phase of this study, the same second order conditional (SOC) pattern as in Meulemans et al.’s (1998) study was used. Despite its smaller number of trials (5 blocks of 84 trials), the results of Meulemans et al.’s (1998) study demonstrated implicit learning of the repeated pat-
tern in both children and young adults. The repeated sequence of ball appearance and trajectory was, 0, 3, 2, 0, 1, 3, 0, 2, 3, 1 with each number representing a quadrant in which the ball appeared. For example, the 0 represented the ball appearing in the lower left quadrant. Three phases were implemented: an acquisition phase to evaluate learning of the sequence; a retention phase to evaluate if learning of the sequence was maintained; and a recognition phase to evaluate the form of learning.

**PROCEDURE**

**Acquisition phase.** This phase consisted of five blocks of 84 trials (a trial was equivalent to one ball). Each block started with 4 random trials (random sequence) followed in series by 10 repeating trials (repeating sequence), 6 random trials, 10 repeating trials, until 84 trials were complete. This mixing of repeating and random sequences was expected to make it less probable that participants became aware of the pattern (Curran, 1997; Meulemans et al., 1998). The participants were instructed to reach with their preferred hand to contact the ball as quickly and as accurately as possible. At the end of each block, participants were informed of their total time to complete the block and were encouraged to obtain an even faster time on the next block.

**Retention phase.** This phase followed after a 30 min filled delay interval. To avoid learning of the sequence within the retention phase, the participants were asked to complete a series of 16 balls, composed of a random sequence (6 balls) and the same repeated sequence (10 balls) that had been presented in the acquisition phase.

**Recognition phase.** Following the retention phase, the recognition phase involved three tasks: the interview, the process dissociation procedure (PDP), and the recognition task.

The interview consisted of a questionnaire that was verbally administered following the retention phase to determine whether or not there was evidence of explicit learning of the pattern. Questions began very generally and then became more specific. They were: “Did you notice anything about this game?” “Did you notice any pattern during the game?” “Did you notice any pattern in the way balls appeared during the game?” and “Do you think there was any pattern repeated during the game?” The purpose of the specific questioning was to determine how much prompting was needed before a participant could identify that they had recognized the presence of a pattern, if at all. If the participant was able to state that they were aware of a pattern early on in the interview, it was hypothesized that a level of explicit learning had occurred. Conversely, if the participant required continued questioning to verbalize awareness of the pattern, it is then hypothesized that learning was more implicit than explicit on the continuum of implicit to explicit learning. Such questioning to determine pattern awareness has been used in previous SRT studies (Howard & Howard, 1997; Howard et al., 2004). However, Shanks and Johnstone (1999) argue that the interview taps into reportable knowledge, so it is not exhaustive and may not completely reflect conscious knowledge. Therefore, two additional methods of determining explicit knowledge have been implemented.

After the interview, participants were told that there was in fact a pattern present during the task. The purpose of the PDP was to dissociate implicit learning from explicit learning (Destrebecqz & Cleeremans, 2001). The PDP consisted of two conditions, one being the inclusion condition and the second being the exclusion condition. In the inclusion condition, participants were asked to reproduce the pattern that was in the acquisition phase. In the exclusion condition, participants were asked to avoid producing the patterned sequence. If participants were able to reproduce the pattern in the inclusion condition and were able to avoid producing the patterned sequence. If participants nevertheless reproduced the pattern in the exclusion condition, it was assumed that the pattern was learned explicitly because they were able to manipulate their knowledge. If participants nevertheless reproduced the pattern in the exclusion condition, this demonstrated that they learned it implicitly as they were unable to manipulate their knowledge and so could not avoid reproducing it (Curran, 2001; Destrebecqz & Cleeremans, 2001).

For the recognition task, participants were presented with 16 sequences of four balls. Half of the sequences presented were “old”, being part
of the repeated sequence whereas the other half of the sequences presented were “new” and had never been seen by participants before. For each of the 16 sequences, they were to answer “yes” or “no” to whether the pattern that the four balls appeared in looked like any part of the pattern that was in the acquisition phase. Once again, this allowed us to determine whether participants had explicitly learned the pattern. If so, they would have been able to correctly recognize it. Such a forced-choice recognition task has been recognized as a valid test of explicit sequence knowledge (Destrebecqz & Cleeremans, 2001; Goschke, 1998; Shanks & Johnstone, 1999). Also, Tunney and Shanks (2003) have found that the binary technique described above is more sensitive than continuous scales.

RESULTS

Acquisition
Anticipation toward the wrong ball, that is movement toward a ball that did not actually appear in that particular corner of the screen, was considered an error. These errors were identified using a freeware computer program (accessed at http://www.health.uottawa.ca/biomech/csb/software/) that allowed for graphical representation of the participants’ movements. The mean number of errors per block for the repeated sequence was 2.31 and for the random sequence was 2.29. There were no significant differences in the number of errors between repeated and random sequences. It is important to note that the response times recorded during these mistakes would no longer be representative of the overall time it took to respond to the stimulus. Therefore, trials corresponding to wrong directions were initially omitted from all calculations of mean response times. However, a repeated measure ANOVA was completed using mean times for repeated blocks with and without errors. The results indicated that the difference in mean times was not significant, \( F(1,10) = 4.755, p < .054 \). For this reason, mean response times with errors included were analyzed.

Further, a technical difficulty with using the virtual reality system was that it did not always record the first touch, so participants sometimes had to reach for a ball twice before the stimulus disappeared. The mean number of these double touches per block for the repeated sequence was 1.2 and for the random sequence was 1.6. The initial response time to the stimulus and corrected times were used in our analysis.

To determine whether there was learning of the repeated pattern, the mean response times for both the repeated and the random sequences were examined using a 2 (pattern) X 5 (block) analysis of variance (ANOVA), with repeated measures on the last factor. Results showed that there was a significant improvement across blocks for both the repeated and random patterns, \( F(4,40) = 20.233, p < .000 \). More importantly, response times were significantly faster for the repeated sequence than for the random sequence, \( F(1,10) = 9.981, p < .010 \), thus demonstrating that learning of the repeated pattern had occurred (Forkstam & Petersson, 2005). Upon closer analysis of the graph, it seems as though the repeated pattern was initially faster than the random pattern in block one. This may be interpreted as a potential confound, with the possibility that the repeated sequence was just an easier movement sequence to perform. To examine this more closely, a comparison of mean repeated and random response times across the 5 random and repeated sequence trials within block one was done. This was examined using a 2 (pattern) X 5 (sequence trial) analysis of variance (ANOVA), with repeated measures on the last factor. We found that the difference in response times between patterns was not significant, \( F(1,10) = .000, p < .996 \), indicating that the mean response times of both sequences were equivalent from the start.

Retention
The retention phase allowed us to determine whether learning of the pattern was maintained. The difference in mean response times between block 5 and retention were examined by using a paired sample t-test. It was found that the mean retention response time was slower than in block 5 (see Figure 2), but that the difference was not significant (\( t = -1.425, p < .185 \)). The difference between repeated and random mean times in the retention phase was also examined. It was found that the repeated sequence continued to be significantly faster than the random sequence (\( t = -2.412, p < .037 \)). These results indicate that learning of the pattern was maintained.
Recognition
This phase of the study was designed to determine whether or not there was evidence of explicit learning. Explicit learning of the repeated pattern was measured via three different tasks. If subjects were unable to demonstrate the learning of the repeated pattern through these tasks, it was assumed that the learning that had occurred was implicit (Curran, 1997).

Interview. All participants except for one demonstrated some level of awareness of a pattern at some point of the interview. Seventy three percent (8/11) of the participants reported awareness of a pattern by the second interview question. Though none of the participants were able to explicitly convey what the repeated pattern was, most appear to have had some awareness of the existence of a pattern.

PDP. Since a SOC sequence was used, the number of three-element chunks that were part of the repeated pattern were calculated for both inclusion and exclusion condition. It is possible that participants produced these sets by chance; however, if participants were able to produce patterns above chance, some level of explicit learning of the pattern can be presumed (Destrebecqz & Cleeremans, 2001). As per Destrebecqz and Cleeremans (2001), chance level was calculated to be 0.33 for this sequence. In examining the PDP results, it was found that 73% of participants (8 out of 11) were able to produce patterns above chance level, possibly indicating the presence of explicit learning. Further examination of the results showed that the beginning and end chunks of the repeated pattern were more frequently recalled. This may be indicative of a serial list position effect, i.e., that it is easier to recall the first and last items on a list (Darley & Glass, 1975). A similar effect has been noted with lists of movements (Wilberg, 1990).

The second condition of the PDP task was the exclusion condition. Unfortunately, results were inadmissible, as all but four individuals produced a pattern that was artificial (e.g., selecting balls in a clockwise direction until the task was completed). Also, one participant failed to follow directions and touched balls twice in a row. Of the three participants analyzed, only one reproduced sets above chance level. This suggests that this participant learned the pattern implicitly and was unable to avoid producing it in the exclusion condition; this same participant also replicated the most sets of threes from the repeated pattern in the inclusion condition.

Sequence recognition task. A one-way ANOVA, with response as the dependent variable and sequence as the factor, was done to determine whether or not participants were able to consistently identify the old and new sequences. Results indicated no significant number of correctly identified sequences (correct identification = no response to new sequences and yes response to old sequences), $F(1, 74) = 1.367$, $p < .244$. This concludes that participants could not discriminate between the old and new sequences.

DISCUSSION
The results of the acquisition phase of the present study indicated learning of the repeated pattern during a gross motor task. Despite the gross motor nature of the task used in this study, the results replicated those of similar SRT studies that have utilized simple motor tasks. Both Howard and Howard’s (1989; 1992) and Cherry and Stadler’s (1995) results using the traditional key press task showed significantly faster reaction times for across blocks for the repeated pattern. It is therefore plausible that implicit learning during a gross motor task occurs in much the same manner as in a simple motor task. Interestingly, the participants in this study appeared to be cautious in their performance, as they made few errors in both the random and repeated conditions. Such cautiousness was also noted by Howard & Howard (1997) in their elderly participants.

The results of the present study also demonstrated that learning of the repeated pattern was maintained after a 30-minute interval. These findings are similar to those produced by Cherry and Stadler (1995). Meulemans et al. (1998) also included a retention task that was completed one week following the acquisition phase and showed that the mean reaction times were similar in both sessions.

During the interview, many of the older participants verbalized a level of awareness of the pattern being present; however, none were able to report it. This is typical of traditional SRT
studies (Howard & Howard, 1989; 1992). Some level of explicit learning was also demonstrated during the PDP task. Eight out of eleven participants recalled an above-chance number of chunks from the repeated pattern during the inclusion condition, and two out of the three participants analyzed for the exclusion condition were successful in avoiding chunks from the repeated pattern. These findings are contrary to those of Howard and Howard (1989; 1992), where the older adults showed little pattern learning (below chance level) compared to the younger adults. Both older and younger adults performed more poorly than younger adults when it came to identifying the actual pattern or parts of it (Howard & Howard, 1989). Harrington and Haaland (1992) used a task where participants learned a pattern of different hand postures in response to lights being used as cues. Unlike previous pattern-detection studies, the elderly in their study demonstrated equivalent impairment in both implicit and explicit learning of the cognitive-motor sequence. The processing speed theory predicts that older subjects will be less likely to spontaneously notice and explicitly memorize the sequence. This hypothesis was considered by the study's authors, but was not found to be valid in explaining the results (Willingham, 1998).

As with the present study, not only did most participants in the hand posturing study report awareness of a pattern, but recall in the free recall test exceeded chance level, indicating explicit learning. However, unlike the Harrington and Haaland (1992) study, the older adults in the present study showed some evidence of implicit learning of the sequence (as noted in the recognition test and the exclusion condition of the PDP task). Perhaps the greater movement times necessitated by the reaching task used in the present study and the hand posturing task in the Harrington and Haaland (1992) study facilitated this awareness and improved pattern identification. It has been shown that responding in an SRT task results in sequence learning, while simply observing the sequence on screen does not (Howard, Mutter, & Howard, 1992; Kelly & Burton, 2001). Willingham (1999) showed that the sequence learning in Howard et al. (1992) was actually facilitated by explicit knowledge of the sequence. Once participants who had significant explicit knowledge were excluded from analysis, participants who merely observed the stimuli did not show implicit sequence knowledge. Interestingly, observation of a model performing the SRT task has been shown to result in sequence learning as much as physical practice (Heyes & Foster, 2002); the authors caution that observation may result in greater explicit learning. During their investigation of the response structure of an upper arm movement sequence, Park and Shea (2005) found that all participants demonstrated strong explicit knowledge of the repeated sequence.

Perhaps the reaching task’s increased movement time facilitates an observational component that in turn may increase explicit awareness. It is also plausible that, unlike in Harrington and Haaland’s (1992) experiment, implicit learning was maintained in the SRT reaching task because pattern learning focused on response location; whereas the hand posturing task required participants to learn different motor responses, which requires greater attention. The increased attentional demand of the hand-posturing task was put forth as a possible explanation for the poor sequence learning in their study (Harrington & Haaland, 1992).

Finally, similar to Meulemann et al. (1998), the results of the sequence recognition task in the present study indicated that participants were not able to differentiate between old and new sequences, despite the interview and PDP findings. When participants were asked to verbally demonstrate explicit learning of the pattern, they were unable to convey any consistent awareness of the pattern. Considering these findings, it may be that greater movement times increased awareness of the presence of a pattern, but not enough to identify it. It is plausible that the greater movement time compensates for the slower processing speed. Further research is necessary to determine if tasks with different movement times influence the gain in explicit knowledge. Perhaps tasks with greater movement times facilitate awareness. This may be an important aspect to consider in rehabilitation for teaching various motor abilities and daily tasks.
CONCLUSION

These study results show that older adults can learn a repeated pattern during a gross motor SRT task. Whether the learning during a gross motor SRT task in the older adults compares to learning in young adults and children, as it has been shown in simple tasks, remains to be seen. The participants in this study did not appear to be cognizant of the repeated pattern per se; however, they did demonstrate a greater awareness of the presence of a pattern than in previous studies using the more simple key press task. Whether movement time required for a task influences whether learning remains implicit or becomes explicit needs to be explored. This will have implications not only on the understanding of the learning of novel motor tasks in the elderly, but on what instructional methods best facilitate each type of learning.

REFERENCES


**CONTACT**

Rose Martini, PhD, OT(C)
Assistant Professor, Occupational Therapy Program, School of Rehabilitation Sciences Faculty of Health Sciences University of Ottawa 451 Smyth Rd. Ottawa, Ontario, K1H 8M5 Tel. (613) 562-5800 ext. 8028 Fax: (613) 562-5428 E-mail: rose.martini@uottawa.ca