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Interference Effects on Procedural Memory: An Assessment of Problem-Solving Task Performance

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Three experiments were conducted to assess interference effects acting on procedural task learning and performance using the Tower of Hanoi puzzle. In Experiment 1, participants in the no-interference group completed the Tower of Hanoi faster than the retroactive interference groups, with no differences between the types of tactile interference. These results indicate that retroactive interference may hinder procedural task performance but does not differentiate between consolidation and retrieval. Experiment 2 addressed retroactive interference placement by manipulating the delay prior to the interference task. Interfering with only consolidation or recall did not produce interference effects, but qualitative feedback regarding emotion raised questions about the effects of affect induction. Experiment 3 attempted to address the influence of a proactive and retroactive affect induction technique but did not produce a dichotomous happy versus neutral effect. Overall, the series of experiments conducted provides a conceptual replication of some previous research while contradicting other findings. This research not only extends our current understanding but also highlights the need to continue to explore factors that may influence the practice or acquisition of novel procedural tasks.

Keywords: procedural learning, interference, affect, memory, Tower of Hanoi

Memory refers to the ability of an organism to store, retain, and retrieve information over time (Atkinson & Shiffrin, 1968; Baddeley & Hitch, 1974; Cowan, 1999). It is a complex process that involves multiple brain regions and neural networks (for review, see Squire et al., 1993). There are several types of memory, including working memory, short-term memory, and long-term memory. Working memory refers to the cognitive system responsible for temporarily holding and manipulating information in the mind to perform complex cognitive tasks, while long-term memory refers to the storage and retention of information over a prolonged period, ranging from minutes to years, that is retrieved when needed (Cowan, 2008). Long-term memory is further divided into different subtypes, such as episodic memory, semantic memory, and procedural memory.

Procedural memory is the type of memory that enables us to learn and recall skills and procedures necessary for daily life, from simple actions such as brushing our teeth to complex activities such as playing an instrument or driving a car. This type of memory is critical for our ability to perform tasks efficiently and accurately without conscious effort or thought. It is also involved in the acquisition of new skills and the refinement of existing ones, making it essential for personal and professional development (Squire et al., 1993).

Comparing Procedural Memory to Other Types of Memory

Procedural memory is often implicit, meaning it operates outside of conscious awareness and without deliberate effort (Squire et al., 1993). When performing a skilled task, the individual is not necessarily aware of every step involved in the process, but rather, their body and mind learn the sequence of movements and actions through repetition and practice (Fitts, 1964). This type of memory is often referred to as muscle memory since the movements become autonomous and are often performed with little or no conscious thought (for review, see Packard & Knowlton, 2002).

Another key feature of procedural memory is its resistance to forgetting (Squire et al., 1993). Once a skill or procedure has been learned and stored in procedural memory, it can be retrieved and executed with little effort or conscious thought, even after years of disuse. This is because procedural memory is primarily stored in the basal ganglia, cerebellum, and motor cortex regions of the brain, which are involved in motor control and movement planning (Packard & Knowlton, 2002). This is in stark contrast to episodic and semantic memories.

Episodic memory is a type of long-term memory that involves storing and retrieving personal experiences, events, and episodes (Baddeley, 2000). Examples of episodic memory include remembering one's first day of school, a family vacation, a significant life event, or simply how to complete a puzzle. Episodic memory. involves conscious effort and is associated with the hippocampus and related brain regions (Tulving & Markowitsch, 1998). Another trademark of episodic memory is that it is declarative, meaning that it involves conscious recollection. This is a similarity that episodic and semantic memory share (Tulving, 1999).

Compared to episodic memory, semantic memory involves the storage and retrieval of general knowledge and information about the world rather than specific events (for review, see Tulving, 1999). Semantic memory is associated with the neocortex and related brain regions, and it differs from other forms of memory in that it is more abstract (for review, see Allen & Fortin, 2013). However, extensive research indicates that episodic and semantic memory is prone to interference (Eakin & Smith, 2012; Flaisch et al., 2016; Wohldmann et al., 2008; Yang et al., 2013).

Interference in Different Forms of Memory

Various factors can influence the accuracy and reliability of stored information. One such factor is interference, which can disrupt the encoding or retrieval of information, leading to memory errors or loss (Unsworth et al., 2013; for review, see Robertson, 2012). Interference can be broadly classified as proactive and retroactive. Proactive interference (PI) is where previously learned information interferes with the encoding or retrieval of new information, while retroactive interference (RI) is where newly learned information interferes with the rehearsal or retrieval of previously learned information. For example, imagine trying to remember a previously learned list of items but then learning a new list of similar items. The new list may retroactively interfere with the retrieval of the old list, making it more difficult to remember.

Unsworth et al. (2013) conducted a series of experiments to understand how PI and RI affect memory recall for word lists. In Experiment 1, participants recalled words from either one or two lists. Both interference types caused lower recall, more intrusions (incorrect items recalled), and longer recall times. The hypothesis that participants might search both lists simultaneously but eliminate intrusions before recall was tested in Experiment 2. Participants recalled words from both lists, resulting in roughly equal intrusions from Lists 1 and 2. Rejecting intrusions was harder, and clustering indicated contextual cues helped recall. Experiment 3 examined recall with varying set sizes. Recall of Lists 1 and 2 was worse than control lists. Recalling both lists had worse results than recalling only one, replicating the "only effect" where combining lists led to larger search sets. Participants still included irrelevant items, causing interference. Finally, Experiment 4 used distinct categories for each list. Recall outcomes were similar for all three lists, suggesting distinct categories focused on participants' search and reduced interference, resulting in comparable recall without intrusions.

Unsworth et al.'s (2013) results also might suggest that the effects of RI vary depending on the type of information being retrieved. For example, RI may have a greater effect on semantic memory than episodic memory. Another factor that has been well documented to influence the extent of RI in humans (Osgood, 1946; Wickelgren, 1965) and non-human primates (Medin et al., 1980) is the degree of similarity between the old and new information. The greater the similarity, the more likely it is that RI will occur. A third factor is the amount of time that has elapsed since the new information was learned, with more recently learned information being less susceptible to RI (Reyna, 1995). Yet, these patterns of results might be limited to declarative forms of memory.

The mechanisms underlying RI in procedural memory are not fully understood. However, studies suggest that RI may affect different stages of procedural memory processing, including encoding or acquisition, consolidation, and retrieval (for review, see Robertson et al., 2004). Acquisition refers to the initial learning of a new motor skill. Studies have shown that RI can impair the acquisition of procedural memory. For example, in Brashers-Krug et al. (1996), participants learned to compensate for velocity-dependent forces on a manipulandum and were immediately tested on a second task. Learning the second task within a short time period interfered with the retention of the first task. However, this RI was gradually reduced with the increase in the time interval between the two tasks. The study provides evidence that human motor memory is transformed rapidly with time and in the absence of further practice, in addition to providing evidence that RI occurs in tasks that rely heavily on procedural memory. This means that learning a new motor task can interfere with the consolidation of a previously learned task, making it more difficult to acquire the new task. This also suggests that RI may interfere with the encoding or consolidating new motor skills, lead ing to memory errors or loss. However, Brashers-Krug et al. did not differentiate between consolidation and retrieval.

Similar results are reported by Friedman and Korman (2016). In their study, participants completed a finger opposition task where they touched their thumb and another finger in a specific sequence. They first did four test trials and then 10 training trials with the sequence shown on the screen. Then, half of the participants did an interference training session with a different sequence. All participants were tested again 24 hours later on the original sequence and a different sequence with both hands. Analyses suggested that RI prevented delayed gains in correct sequences but not accuracy and that two types of processes contributed to procedural learning: one sensitive to interference (consolidation) and one independent (recall). Yet, similar to Brashers-Krug et al. (1996), Friedman and Korman (2016) did not attempt to interfere with the recall or retrieval process independent of other stages.

Retrieval refers to the process of accessing and using previously learned information. When further scrutinized, Brashers-Krug and colleagues's (1996) results also appear to suggest that RI may not affect the retrieval of procedural memory, but their methods do not address this directly. More recent research has shown that RI can interfere with the retrieval of a previously learned task, possibly across memory types, making it more difficult to execute the previously learned task. Gagné and Cohen (2016) used a randomized controlled trial to investigate how interference between memory systems affects skill acquisition. Participants were assigned to one of four groups, each receiving a different combination of verbal and motor interference tasks during a finger-tapping sequence learning task. The authors used various measures to assess performance, including reaction time, accuracy, and the number of correct sequences produced. Participants were tested on the task immediately following the learning phase and again 24 hours later. Only the control group showed offline improvement, and introducing a visuospatial task before motor recall eliminated the gains, thereby suggesting interference between memory systems during subsequent motor recall. This suggests that various factors may cause RI and that RI may also negatively impact some of the retrieval processes of previously learned motor skills. Within other types of memory, the idea that other factors such as similarity, time, and the amount of practice influence performance is not new, but these are not the only possible contributors to performance.

Emotion and Memory

Emotional state can influence our ability to learn different types of information, including a new procedural skill. Procedural memory is closely linked to the brain's motor system, which is also involved in processing emotions (Packard & Knowlton, 2002). Studies have shown that emotional arousal can enhance memory formation and retention. For example, LaBar and Phelps (1998) found that emotionally arousing words resulted in better memory retention than neutral words. The authors suggested that emotional arousal enhanced the consolidation of semantic memory. Conversely, Rimmele et al. (2011) found that participants who were exposed to negative emotional stimuli reported better memory retention than those who were exposed to neutral stimuli, even though their performance was actually worse. These mixed results suggest that our understanding of how emotion interacts with memory is lacking, especially within procedural memory paradigms or when emotion is evoked using different methods

Regarding PI, Yang et al. (2011) induced positive affect in participants by giving them candy as a token of appreciation. Participants' memory was then tested using word- and operation-span tasks, presented in increasingly difficult order. The word- and operation-span tasks were 10 trials each, with two trials at each set size ranging from three to seven presented in random order. An increase in positive affect appeared to moderate memory improvements for words and numbers. Although similar anecdotal (e.g., an athlete reporting that feelings influence performance) and empirical evidence suggest similar effects may exist within procedural memory (Steidl et al., 2006), our understanding is far from comprehensive. However, one study does find an effect of emotion on procedural skill learning within offline consolidation processes. Javadi et al. (2011) recruited 99 participants who were divided into nine groups, with each group having a combination of retention type and emotional content conditions. Participants completed a mirror-tracing task where stimuli included faces that were negative, positive, or neutral in expression, with a significant difference between the valence scores of positive and negative images but no significant difference in the arousal scores. The experiment was composed of two sessions (training and testing) with either a 12- or 24-hour retention interval. Participants also completed a finger-tapping task, which was used to evaluate alertness. The results suggest negative content during encoding improves later performance on the mirror-tracing task more than neutral or positive content. In fact, participants who learned with negative images had greater skill improvement over time compared to those who learned with neutral or positive images. Another relevant but secondary finding suggests that alertness does not play a role in performance differences, which might suggest that physiological arousal is not as important as other factors. Although the most basic forms of PI and RI are not widely disputed, there is still some debate on the effects of emotion on learning, as the research findings have not always been consistent. Research has found positive and negative emotional states may enhance learning (Javadi et al., 2011; LaBar & Phelps, 1998; Yang et al., 2011). However, other studies have found that negative emotional states may hinder learning (Flaisch et al., 2016; Rimmele et al., 2011). Furthermore, interactions between variables such as level of skill expertise and affective tone have not been widely examined outside of video game literature (Weinreich et al., 2015), leaving gaps in the literature that should be addressed by basic research.

Overall, while there is some debate on the effects of emotion on procedural learning, it is clear that emotional states can impact the learning and retention of procedural skills. The exact nature of this impact, and whether it is positive or negative, may depend on various factors, such as the type of task, the individual's level of expertise, and the specific emotional stimuli involved. More research is needed to fully understand the complex relationship between emotion and procedural learning. To this end, we report on a series of three experiments conducted to (a) replicate the existing literature that demonstrates RI can directly impact procedural learning and performance, (b) clarify the importance and independence of the consolidation and recall processes within procedural paradigms, and to (c) explore the specific impact of unexpected rewards on novel procedural task acquisition and performance.

Experiment 1

Experiment 1 attempted to replicate previous literature that establishes RI within procedural paradigms (Brashers-Krug et al., 1996; Friedman & Korman, 2016; Gagné & Cohen, 2016; Robertson et al., 2004). We used the Tower of Hanoi as the target procedural memory task (see Figure 1), because it requires learning a specific set of rules and steps (Vakil & Heled, 2016) which can be taught instead of used as a measure of problem-solving. We expected that peg puzzles (see Figure 2) would produce the most interference due to their similarity to the Tower of Hanoi (Osgood, 1946; Wickelgren, 1965). Ring puzzles (see Figure 3) are less like the Tower of Hanoi and were not expected to cause the same level of interference, but interference was still expected to occur compared to the writing control task. Therefore, the hypotheses for Experiment 1 were as follows:

1. RI that occurs between learning the Tower of Hanoi and the final performance test was expectedto cause completion time (s) to increase significantly within the peg and ring interference groups when compared to the no interference control group.
2. Participants in the ring interference group were expected to complete the task faster than participants in the peg interference group when retested on the Tower of Hanoi.

Method

Participants

One hundred eight participants (30 men, 78 women; 18–50 years of age) were recruited via a bulletin board flyer and received course credit for their participation. Data from one participant in the ring group were excluded because they could not complete the post-interference Tower of Hanoi task. Data from one participant in the peg group were removed due to a pre-interference completion time that was over three standard deviations from the mean. Data from two more participants (one peg group, one ring group) were excluded for having a post-interference completion time that was over three standard deviations from the mean. Therefore, data from 104 participants were included in the final analyses (see Table 1).

Materials

The Tower of Hanoi (see Figure 1) required participants to move a tower of discs from a start peg to a target peg. There were two rules for moving the discs: (a) only one disc could be moved at a time and (b) a larger disc could not be placed on a smaller disc. The Tower of Hanoi task varies in difficulty based on the number of discs used. The minimum number of moves the puzzle can be completed in is calculated using the equation $f(x) = 2n-1$, where $f(x)$ represents the fewest number of moves and n equals the number of discs. Typically, the puzzle consists of three pegs and three disks. Difficulty increases as the number of discs increases. To make the task moderately difficult, the Tower of Hanoi task used in this study consisted of three pegs and four discs. Successful completion of the Tower of Hanoi requires a set procedure that must be carried out in a specific order. The specific sequence extends the task beyond motor memory and forces participants to use spatial problem-solving skills and procedural memory.

Some participants in the study worked with either three different peg puzzles or eight different ring puzzles, each with a unique goal and set of rules. The three peg puzzles (see Figure 2) were the in-line puzzle (left panel), the elimination puzzle (center panel), and the addition peg puzzle (right panel). The in-line puzzle required participants to move pegs so that they switched sides, while the elimination puzzle involved removing all but one peg from play by jumping one over another to an open spot. The addition peg puzzle required filling all holes but one by tracing preset lines between them, with the caveat that a move could not be made if it led to a previously filled slot. For the ring puzzles (see Figure 3), participants had to disconnect two linked metal pieces by twisting, sliding, or pulling them apart, using similar strategies for each puzzle. Completion times in seconds were recorded using a stopwatch.

Procedure

First, each participant learned how to complete the 4-disc Tower of Hanoi puzzle with verbal, written, and visual instructions. Written instructions were given to each participant and read aloud, briefly outlining the objective and rules of the task. The visual instructions (see Figure 4) were provided in the form of an animated .gif (Karwath, 2005), and by one researcher demonstration. The discs were color-coded by size. Once the animation began, the discs moved from the start peg, following the best sequence possible (a total of 15 moves) to complete the task. The video lasted approximately 30 s and was replayed six times for each participant. After the instruction, participants were allowed two min to practice the Tower of Hanoi without the animation. This training method is modified slightly from Vakil and Heled (2016). Participants then ran through the Tower of Hanoi another time, completing it as quickly and efficiently as possible. Out of view of the participant, the researcher recorded the completion times (s) and the total number of moves made.

Following the practice phase, participants were randomly assigned to complete one of the three tasks: Writing control, ring puzzles, or peg puzzles. During a 10-min period, control participants wrote a detail-oriented description of the events of their day. If they finished early, they were instructed to write a detailed description of their favorite place on campus. Participants in the ring and peg puzzle groups solved as many of their respective puzzles as possible within 10 min. For both of those groups, puzzles were introduced verbally and in writing, with one visual demonstration by the experimenter. Participants repeated puzzles if they completed all of them within the 10-min period. Immediately following the interference task, Tower of Hanoi's performance was assessed again using the same method described for the pre-interference assessment.

Results

Homogeneity of variance was not violated for Before Interference completion time (p = .776) and completion time data appeared to be normally distributed. An initial analysis of variance (ANOVA) comparing completion times between groups before interference showed the effect of the Interference Group was not significant, $F(2, 101) = 0.496$, $p = .611$, $\eta^2 = .010$, suggesting that performance did not differ across groups prior to completing their respective interference or control task. Performance on the Tower of Hanoi was then examined using a series of 3 (Interference Group: Control, Ring Puzzle, Peg Puzzle) x 2 (Test Trial: Before Interference, After Interference) mixed ANOVAs on the dependent variables completion time and number of moves (power = 1.0). Homogeneity of variance was not violated for After Interference completion time (p = .615), Before Interference number of moves (p = .287), or After Interference number of moves (p = .158). Both of the main effects of Interference Group, $F(2, 101) = 3.225$, $p = .044$, $\eta_p^2 = .060$, and Test Trial, $F(1, 101) = 17.587$, $p < .001$, $\eta_p^2 = 0.148$, were significant on completion time. The Interference Group x Test Trial interaction was also significant on completion time, $F(2, 101) = 12.883$, $p < .001$, $\eta_p^2 = 0.203$. None of the main effects were significant on the number of moves, which suggests that all participants not only learned the puzzle but retained the steps equally well. Interpretations of the significant effects on completion time are provided below.

A series of t-tests using Tukey's correction were used to follow up on the significant main effect of the Interference Group. The Control and Ring Puzzle groups were significantly different (p = .038). Completion time was longer in the Ring Puzzle group (M =

23.914, SD = 6.807) than in the Control group (M = 20.472, SD = 6.077), regardless of Test Trial. No other comparisons were significant. The significant main effect of Test Trial indicated that completion time was longer After Interference (M = 23.420, SD = 7.609) than Before Interference (M = 21.080, SD = 5.503), hinting that at least one group's performance changed. Simple effects were run to follow up on the significant interaction effect and to further explore both within- and between-group differences. The simple effects of Test Trial at Ring Puzzle, $F(1, 101) = 22.61$, $p < .001$, $r = .44$, and Peg Puzzle, $F(1, 101) = 16.82$, $p < .001$, $r = .32$, were significant. Completion times were longer after completing the ring and peg puzzles than before completing them (see Figure 5). In contrast, the simple effect of Test Trial at Control was not significant, meaning there was no difference in completion time before and after performing the control task. Simple effects also indicated that differences were driven by completion times being different across groups following their respective tasks, $F(2, 101) = 7.92$, $p = .001$, while no differences were observed in completion times before the conditions deviated, $F(1, 101) = .500$, $p = .611$.

Experiment 1 Discussion

Previous research has shown the potential for RI in procedural memory (Brashers-Krug et al., 1996; Friedman & Korman, 2016; Gagné & Cohen, 2016; Robertson et al., 2004). Experiment 1 aimed to examine the effect of interference tasks on the retrieval of procedural memory of the Tower of Hanoi puzzle. Results showed that the writing control group completed the Tower of Hanoi puzzle faster than the peg and ring interference groups after the respective interference tasks. However, the peg task, which was subjectively more similar to the Tower of Hanoi than the ring task did not produce larger interference effects. Notably, the results also suggested that the level of interference did not affect the participant's total number of moves. These results support Hypothesis 1, but Hypothesis 2 was not supported. Experiment 1, like other research, did not compare the effects of consolidation and retrieval on RI (Brashers-Krug et al., 1996; Friedman & Korman, 2016). Experiment 2 was conducted to investigate the importance and potential independence of these processes in procedural memory and skill acquisition.

Experiment 2

Javadi et al. (2011) focused on retrieval as the point of action for RI. Another important process potentially affected by RI is the consolidation of newly acquired memories (Brashers-Krug et al., 1996; Friedman & Korman, 2016). Consolidation aids in memory retention by organizing material in working memory and preparing it for transfer into long-term memory (Squire, 1986). Without the consolidation process, memory would not transfer. This study aims to address the effects of RI on the differentiable processes of consolidation and retrieval by examining both potential points of action within the same RI paradigm as Experiment 1. Using the Tower of Hanoi again as a target task, our hypotheses for Experiment 2 were as follows:

1. Immediate forms of interference were expected to produce the greatest performance decline due to the learner's inability to consolidate newly learned information (Brashers-Krug et al., 1996; Friedman & Korman, 2016).
2. Delayed interference, acting directly before retrieval, was expected to have no performance-inhibiting effects due to allowing consolidation to complete automation of the procedural task (Javadi et al., 2011).
3. Participants in the control group were expected to perform better than participants in any other condition when retested on the Tower of Hanoi.

Method

Participants

One hundred and thirty-two participants (51 men, 81 women; 18–30 years of age) were recruited via the university's online research recruitment website and received research credit for their participation. Four participants were removed from the analysis due to not following the rules for completing the Tower of Hanoi puzzle, data from two more participants were removed due to incomplete data collection, and data from six more participants were removed due to their initial test completion time (s) being over three standard deviations from the mean. Therefore, a total of 120 participants were included in the final analyses (see Table 2).

Materials

The same 4-disc Tower of Hanoi puzzle that was used in Experiment 1 was used in Experiment 2. In the interference conditions, participants worked with ten different ring puzzles instead of eight. Completion times in seconds were recorded using a stopwatch.

Procedure

The progression for Experiment 2 was similar to Experiment 1 with a few minor modifications. Each participant learned how to complete the 4-disc Tower of Hanoi puzzle following the same procedure as in Experiment 1. Participants were then instructed to complete the Tower of Hanoi again, completing it as quickly as possible and in as few moves as possible. Out of view of the participant, the researcher recorded pre-test completion time (s) and total number of moves.

Following the practice phase, participants were randomly assigned to complete one of the three conditions. During a 13-min period, no interference participants wrote a detail-oriented description of the events of their morning. If completed before time expired, they were asked to describe their favorite location at the university. Participants in the immediate interference group solved as many ring puzzles as possible within 10-min immediately following the pre-test, then had a three-min waiting period. Participants in the delayed interference group waited three minutes after the pre-test, and then were instructed to solve as many ring puzzles as possible within 10 minutes. Ring puzzle instruction was the same as in Experiment 1. Immediately following the experimental phase, Tower of Hanoi's performance was assessed again using the same method described for the pre-test assessment.

Results

The pre-test number of moves between groups was examined to gauge similarity in levels of mastery across groups. Homogeneity of variance was violated (p = .001) but completion times appeared to be normally distributed and the achieved power was .999. A Kruskal-Wallis H test indicated the median pre-test number of moves did not differ across conditions, $\chi^2(2) = 0.594$, $p = .743$. Homogeneity of variance was also violated for pre-test completion times (p = .029) and non-parametric tests were used for all subsequent analyses. A Kruskal-Wallis H test suggested that neither pre-test, $\chi^2(2) = 0.061$, $p = .970$, nor post-test, $\chi^2(2) = 0.150$, $p = .928$, completion times differed across groups, meaning the groups performed the Tower of Hanoi similarly before and after any intervention. Within-group performance between pre-test and post-test completion times was examined using a series of Wilcoxon signed-rank tests which suggested a significant difference within the Immediate Interference group ($z = -2.197$, $p = .028$, $r = .571$), with median post-test completion times (Mdn = 19) being faster than median pre-test completion times (Mdn = 21). All other comparisons were not significant.

Exploratory analyses conducted after removing all participants whose pre-test completion times were over three standard deviations from the mean of Experiment 1's Before Interference completion times yielded the same overall result, except that no significant difference was observed in the Immediate Interference group when comparing median pre-test completion times to median post-test completion times.

Experiment 2 Discussion

Experiment 1 indicated procedural memory performance can decline when RI tasks are introduced. Experiment 2 did not reveal the same findings when a three-min waiting period was added either immediately after the pre-test or immediately before the post-test. Offline performance gains were observed within the Immediate Interference group while performance did not change within the Control and Delayed Interference groups. These gains might be explained by offline practice, but previous research has only observed these gains within consolidation, suggesting that interfering with retrieval seems to, at least initially, cancel out these gains (Gagné & Cohen, 2016; Javadi et al., 2011). This highlights the importance of work implicating retrieval as an important yet separate mechanism within procedural memory performance and skill acquisition, suggesting that retrieval is less susceptible to RI than previously reported (Javadi et al., 2011). Experiment 2 suggests RI acting on the consolidation process apart from the retrieval process yields different results as compared to acting on both processes. However, another important factor was highlighted during the debriefing process.

Many participants noted that the ring puzzles elicited frustration. Experiment 2 did not quantify emotion as a possible variable acting on performance, but feelings of frustration may have inadvertently enhanced RI within Experiment 1 as other experiments have shown (Flaisch et al., 2016; Rimmele et al., 2011; Weinreich et al., 2015). However, participants did not provide similar informal feedback after completing Experiment 1. Experiment 2 may have also inadvertently introduced boredom or decreased motivation, factors that have been found to influence both learning and memory (Moore et al., 2014), although this is contrasted by research suggesting alertness does not impact procedural performance (Javadi et al., 2011). The mixed results warranted further research to address why RI did not occur and to examine potential influences of emotion observed in previous research (Javadi et al., 2011; Steidl et al., 2006).

Experiment 3

Previous research across memory types has implicated emotion as a factor that moderates performance (Flaisch et al., 2016; Javadi et al., 2011; LaBar & Phelps, 1998; Packard & Knowlton, 2002; Rimmele et al., 2011; Yang et al., 2011), with interventions ranging from emotionally-valenced images or word lists and the receipt of an unexpected gift. However, the research discussed earlier suggests that affect induction has mixed results and the effects are observed as both PI and RI. Experiment 3 was designed to address the implications of positive affect induction via receipt of an unexpected gift either before (PI) or after (RI) learning a novel procedural skill. We hypothesized the following:

1. Positive affect such as joy or happiness was expected to improve test performance regardless of placement (Javadi et al., 2011; Yang et al., 2011).
2. Improvements in performance were expected to be accounted for by an improved ability to learn the task (Yang et al., 2011).
3. Changes in alertness were not expected to impact skill acquisition or retrieval (Javadi et al., 2011).

Method

Participants

Seventy-eight participants (33 men, 45 women; 18-24 years of age) were recruited. Participants received General Psychology course credit and a $10 Amazon.com gift card for participation. Data from two participants were removed after the manipulation check analysis due to worsening completion times during practice. Data from one outlier was removed within the Delayed Gift group based on the first timed test immediately following the practice phase being greater than three standard deviations from me mean. Data from three more participants were removed due to incomplete data collected, and therefore up to 72 participants were included in the final analyses (see Table 3).

Materials

The Tower of Hanoi was also used in Experiment 3. However, participants learned the 3-disc procedure. A transfer task was added which utilized the 4-disc procedure that was used in Experiments 1 and 2. The Positive and Negative Affect Schedule Expanded Form (PANAS; Watson & Clark, 1994) measured self-reported state affect during the experiment. Participants rated to what extent they agreed with statements with either positive or negative connotations. Higher scores on either positive affect words or negative affect words correspond to either higher positive affective tone or higher negative affective tone respectively. Within the general dimension portion, 10 responses were coded as general positive affective words while 10 others were coded as general negative affective words. Positive and negative emotionally charged words were broken down further into subgroups and categorized to analyze these additional dependent variables: joviality, attentiveness, sadness, fatigue, and surprise. These subgroups were identified logically as pertinent to this study while other subgroups such as fear, hostility, and shyness were excluded.

Procedure

Each condition's specific procedural sequence is depicted in Figure 6. One control group first completed the PANAS. Next, these participants were taught how to complete the 3-disc Tower of Hanoi puzzle with verbal, written, and visual instructions. Written instructions were read aloud and given to each participant briefly outlining the objective and rules of the task. Visual instructions were provided in the form of one researcher demonstration. After instruction, all participants were allowed five minutes to practice the Tower of Hanoi. The number of practice trials and successful completions during practice were recorded. Completing the puzzle or restarting marked the beginning of a new practice trial. Initial test performance on the Tower of Hanoi puzzle was measured (s) out of sight of the participant. The total number of moves was not counted as participants were allowed more practice time, and this should only have increased puzzle mastery. Immediately following learning and initial testing participants read a psychology magazine for five minutes. Immediately following, participants were retested on the Hanoi puzzle. Following the second testing phase, transfer was tested using the 4-disc version of the Tower of Hanoi with no instruction. After the transfer measure, participants were awarded a $10.00 Amazon.com gift card. Another control group followed a similar process except they did not complete PANAS before learning the Tower of Hanoi. Instead, participants in this group completed the PANAS after learning instead of a five-minute waiting period. One experimental group followed the same process as the first control group except participants were awarded a $10.00 Amazon.com gift card before completing the PANAS. A second experimental group followed the same process as the second control group except participants were awarded a $10.00 Amazon.com gift card before completing the PANAS.

Results

PANAS

A series of 2 (Affect: positive, neutral) x 2 (Placement: before learning, after learning) independent groups ANOVAs were used to examine the following dependent variables: General positive, general negative, joviality, attentiveness, sadness, fatigue, and surprise. Homogeneity of variance was not violated for any of the affective variables and the distributions appeared to be normal. The achieved power was not as high as in other analyses but was sufficient: .817. Results indicated a significant main effect of Placement on attentiveness, $F(1, 71) = 6.441$, $p = .013$, $\eta_p^2 = .087$ (see Figure 7). On average, attentiveness was higher after learning ($M = 14.971$, $SD = 3.339$) than before learning ($M = 13.216$, $SD = 2.583$) free of the affective condition. No other main effects or interactions were significant.

Practice

Each participant was required to complete at least two of the practice trials being analyzed for their data to be included in the practice trial analyses. Five participants were excluded from all practice trial analyses (two from control group 1, two from control group 2, and one from experimental group 1), leaving up to 67 participants for analyses of the practice phase while achieving power = 1.0.

A 2 (Affect) x 2 (Placement) x 2 (Practice: practice two, practice three) mixed ANOVA was conducted to examine completion time differences between practice trials and across conditions. Homogeneity of variance was not violated for either Practice Two completion time ($p = .325$) or Practice Three completion time ($p = .077$), and sphericity was assumed. Practice had a significant main effect on completion time, $F(1, 58) = 5.189$, $p = .026$, $\eta_p^2 = .082$. There was also a significant Affect x Practice interaction, $F(1, 68) = 4.18$, $p = .040$, $\eta_p^2 = .071$ (see Figure 9). No other main effects or interactions were significant. Simple comparisons were conducted to follow up on the significant interaction. Results indicated the positive groups' times differed significantly from one practice trial to the other $F(1, 60) = 10.90$, $p = .002$, $r = .39$, with practice three ($M = 16.469$, $SD = 5.486$) being faster than practice two ($M = 19.231$, $SD = 9.964$; see Figure 8). No other simple comparisons were significant.

A power function ($y = kx^n$; $r = .635$, $SD = .233$) and a quartic function ($y = ax^4 + bx^3 + cx^2 + dx + e$; $r = .753$, $SD = .166$) were calculated for each participant's practice period, and the quartic function was determined to have a better-fit coefficient. A 2 (Affect) x 2 (Placement) ANOVA was conducted as a precaution to ensure function fit was not different across conditions, resulting in no significant main effects or interaction. The derivative of each quartic equation was taken and solved at the points equal to the second, third, and fourth practice trial times. These derivatives gave the rate of change for each participant's power curve at each point. The rates of change were analyzed using a 3 (Practice: practice two, practice three, practice four) x 2 (Affect) x 2 (Placement) mixed ANOVA to examine changes in completion time (s). Homogeneity of variance was not violated within practice two ($p = .095$), practice three ($p = .094$), or practice four ($p = .092$). The main effect of Practice, $F(2, 126) = 10.311$, $p < .001$, $\eta_p^2 = 0.141$, on rate of change was significant. Pairwise comparisons for the main effect of Practice indicated changes in completion time differed between practice two and practice three ($p = .006$), practice two and practice four ($p = .006$), and practice three and practice four ($p = .007$). Respectively practice two completion times changed fastest ($M = 0.577$, $SD = 0.1.525$), then practice three ($M = 0.378$, $SD = 1.015$), and practice four ($M = 0.280$, $SD = 0.761$). No other main effects or interactions were significant.

Finally, a 2 (Affect) x 2 (Placement) independent groups ANOVA was used to examine potential differences in the number of attempted practice trials between groups. Unsuccessful trials were included in the analysis. Homogeneity of variance was not violated (p = .706), and neither the main effect of Affect nor Placement on the number of attempted practice trials was significant. In addition, the Affect x Placement interaction was not significant.

Test and Transfer

A 2 (Affect) x 2 (Placement) x 2 (Timed Trial: first test, second test) mixed ANOVA was used to examine differences in performance between conditions and across timed trials. Homogeneity of variance was not violated for Timed Trial completion times (p = .947), and achieved power was 1.0. There was a significant main effect of Placement, $F(1, 68) = 4.339$, $p = .041$, $\eta_p^2 = 0.060$, with completion of the PANAS before learning resulting in slower average test completion times (M = 7.740, SD = 1.608) than when the PANAS was completed after learning the Tower of Hanoi (M = 6.996, SD = 1.579) regardless of affective condition. No other main effects or interactions were significant. The main effect of Placement was explored further using a series of independent sample t-tests comparing the first and the second test completion times based on PANAS placement being either before or after learning, which indicated the significant main effect was due to a difference in the second test completion times, $t(70) = 2.100$, $p = .039$, $d = .495$, with later PANAS placement resulting in faster completion times (M = 7.021, SD = 1.509) than early PANAS placement (M = 7.773, SD = 1.529). No difference arose between the first test completion times. A 2 (Affect) x 2 (Placement) independent groups ANOVA was used to examine the dependent variable of transfer time. Homogeneity of variance was not violated (p = .369), and there were no significant effects.

Experiment 3 Discussion

Previous research has used an unexpected gift of candy to induce a higher momentary positive affect before completing a task (Yang et al., 2011). In this study, a $10 gift card was used. It appears that the manipulation failed to produce the desired effects but there were notable changes in attentiveness. However, these changes are limited to after learning how to complete the Tower of Hanoi. This suggests that the intervention did not have a significant impact on attentiveness, but instead simply engaging in learning a novel puzzle might have caused the increase. In turn, the improvements observed across practice trials between the positive and neutral affective groups might be attributable to non-significant differences in initial practice performance. This post hoc explanation is supported by the evidence suggesting that no group exhibited greater practice trial-to-practice trial performance changes. Therefore, the affective results of this study are largely inconclusive. That being true, it appears that the PANAS placement between the first and second tests may have facilitated performance in some way, but the extent and specific mechanisms of this influence are also unclear. Granted, all groups were able to master the 3-disc version of the puzzle, but transfer performance may have been better if a variable training method was used (Vakil & Heled, 2016). Overall, the changes in attentiveness are particularly interesting and will be covered in greater detail within the General Discussion.

General Discussion

This series of experiments had three main objectives: (a) Replicating existing literature demonstrating the impact of retroactive interference (RI) on procedural learning and performance, (b) clarifying the significance of consolidation and recall processes within procedural paradigms, and (c) exploring the influence of unexpected rewards on procedural task acquisition and performance. Experiment 1 replicated prior research on RI in procedural memory using the Tower of Hanoi task and various puzzles. Our first hypothesis was supported that both interference groups would perform worse than the control group. The amount of interference in the peg and ring groups was similar when participants were retested on the Tower of Hanoi, which was contrary to our second hypothesis. However, Experiment 1 did not differentiate between consolidation and retrieval processes. Experiment 2 aimed to clarify the impact of interference on the consolidation and retrieval processes in procedural memory performance. We hypothesized that immediate interference would lead to the largest performance decline, while delayed interference would have no effect. However, the results were not consistent with that hypothesis. We observed that emotions such as frustration and boredom might have influenced performance, which led to conducting Experiment 3. Experiment 3 did not yield the expected effects, though the interpretation of the results paralleled that of Experiment 2, except for the intriguing differences in alertness observed before and after learning the Tower of Hanoi puzzle.

Affect Induction

Previous research has found that we can induce different affective states using various methods (Flaisch et al., 2016; Javadi et al., 2011; LaBar & Phelps, 1998; Packard & Knowlton, 2002; Rimmele et al., 2011; Yang et al., 2011). While Experiment 3 utilized an intervention based on previous work, we assumed that participant affect would be impacted by the surprise receipt of a $10 gift as compared to a small piece of candy (Yang et al., 2011). Given the results, we must acknowledge that there may be a reason why this particular intervention is not commonly used or reported (Zhang et al., 2014). This may explain why the methods used in Experiment 3 did not produce a clear positive and neutral dichotomy.

Future replication of Experiment 3 should use a different method to change participant affective tone. Zhang et al. (2014) tested four different commonly used affect induction procedures (recall with music, guided imagery, visual images with music, and embodiment) and found that all are effective in inducing both pleasant and unpleasant affective changes. However, some procedures are more effective than others. Viewing evocative photographs while listening to music and recalling an affectively salient event while listening to music were the most effective in inducing a pleasant affective tone, while viewing evocative photographs while listening to music was the most effective in inducing unpleasant affect. Overall, these results suggest that combining evocative images with music is a powerful way to manipulate affective states, while all four methods are equally effective in modifying arousal. Using these methods before learning the Tower of Hanoi, or imposing an effective strategy post-learning, might increase the likelihood of achieving the desired effect. This would provide further insight into if the placement of emotionally-valenced interference impacts various stages of procedural skill acquisition and performance.

Alertness and Procedural Memory

Previous research found that alertness was not a factor in procedural performance changes (Javadi et al., 2011). However, the definition of alertness matters. Previous literature defines 'alert' or 'alertness' in many ways, but we believe the following definition, modified and adapted from Oken et al. (2006) and Shapiro et al. (2006), is both recurrent in the literature and appropriate for this discussion. Alertness refers to a heightened state of readiness or vigilance corresponding to the ability to maintain focus and attention on a task or situation. Javadi et al. (2006) used a self-report questionnaire and a finger-tapping task to measure alertness, whereas in Experiment 3, we used the PANAS. Another main difference is that in Experiment 3, we tracked changes in performance across the acquisition stage. This allowed us to determine what mechanisms might be driving overall performance differences if they arose. The differences in the results of Experiment 3 and those reported by Javadi et al. (2011) warrant further exploration into how the construct of alertness interacts with procedural skill acquisition.

In Experiment 3 we observed that alertness appeared to increase after participants' engagement in learning how to complete the Tower of Hanoi. We cannot attribute these changes to the monetary intervention, and therefore conclude that there is some other relationship between alertness and learning a procedural skill. This brings us back to the definition of alertness, and how previous research has linked it to changes in performance. Much of the early research exploring the role of alertness on memory defined alertness as needing sleep or not (Aguirre et al., 1985; Gorissen et al., 1997; Rogers & Rosenberg, 1990). However, contemporary research has expanded our understanding of alertness to include momentary fluctuations that influence both attentional control and memory processes (deBettencourt et al., 2018, 2019; Keene et al., 2022). We also better understand the neuroanatomical structures responsible for modulating alertness (Ross & Van Bockstaele, 2021; Van Egroo et al., 2022). However, there are still gaps in our understanding of the results of Experiment 3.

To date, there appears to be little or no research that systematically examines the influence of alertness on procedural memory processes. However, we might be able to glean some insight from other memory domains such as long-term memory encoding and working memory. Within these systems, vigilance, or the ability to maintain focus on a given task, can be measured using response time and pupillometry. Faster response times in decision-making tasks and larger pupil size compared to an individual's baseline are predictive of errors. In turn, errors suggest that not enough attentional resources are being allocated to the task. To clarify the relationship between vigilance and working memory, Adam et al. (2015) used the whole report change detection paradigm. Participants were presented with a memory display, followed by a test array, and had to indicate whether it was the same or different. Instead of the standard same/different response, participants were presented with a 3 x 3 matrix of colors and had to select the individual color that appeared at the same location as in the original display. The researchers used a lapse model and an attentional control model to explain fluctuations in performance and found that the attentional control model best explained working memory performance. These findings suggest that attention lapses contribute to individual differences in working memory capacity. Further evidence to support an attentional control explanation was reported by deBettencourt et al. (2019). Participants completed a task in which they had to identify if an array consisted of colored circles or squares by pressing a button. The circles appeared more frequently than the squares, causing errors to occur when participants had to switch to identifying the squares. To measure the relationship between vigilance and working memory, a whole-report color task was added to the task at random intervals. Results showed that attention lapses, identified by faster reaction times, were related to errors in working memory.

Similar observations are made in long-term memory. deBettencourt et al. (2018) had participants complete a task where they identified indoor or outdoor scenes and then performed a recognition memory test with 200 images. Sustained attention was measured using the average reaction time over the previous three trials and was found to predict memory performance. Infrequent images preceded by faster reaction times in the initial decision-making task were less likely to be remembered in the surprise long-term recognition memory task than those preceded by slower reaction times. This suggests that an individual's level of vigilance during encoding affects which memories are formed. These recent studies might also give us insight into the results from Experiment 3, and at least give us an idea of why increases in alertness appear to coincide with procedural skill acquisition. When alert, individuals are more attentive and able to process information more efficiently, which can lead to better retention and retrieval of information. Additionally, alertness can lead to increased motivation (Neigel et al., 2017), which may encourage individuals to engage in more deliberate and focused practice, leading to improved skill acquisition. Furthermore, alertness can increase the capacity for mental flexibility and problem-solving (Greenberger et al., 1971; Ren et al., 2011), allowing individuals to adapt their strategies and approaches to the task at hand. However, we cannot rule out the possibility that simply engaging in a cognitively demanding process, such as procedural skill learning, might inherently increase attentiveness.

Conclusion

Collectively, these experiments offer mixed support for our hypotheses, emphasizing the need for further research employing diverse methods to induce affective tone. Such studies can shed more light on the impact of emotionally-valenced interference at various stages of procedural skill acquisition and performance. Additionally, these experiments underscore the importance of replication in psychology research and highlight the replication crisis, which pertains to the challenges of reproducing published research findings, especially in fields like psychology and other social sciences. Replication promotes transparency, openness, and research reproducibility, facilitating systematic progress in our understanding of the subject, rather than leaving gaps in the literature, as is currently the case with our limited understanding of alertness in procedural memory.

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Table 1

Descriptive Statistics for Experiment 1

Condition		Age		Before interference				After interference			
				Completion time (s)		Number of moves		Completion time (s)		Number of moves	
	N	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	36	21.06	2.51	21.28	5.15	15.42	1.38	19.67	6.86	15.53	1.23
Ring	35	22.40	6.96	21.63*	5.77	15.57	1.58	26.20*	7.07	16.03	2.56
Peg	33	20.30	4.48	20.33*	5.67	15.24	0.75	24.39*	7.52	15.58	1.48
Total	104	21.27	5.01	21.10	5.50	15.41	1.29	23.37	7.61	15.71	1.85

Note. This table displays the descriptive statistics of the final data used in Experiment 1, after initial data removals, and separated by condition.

* Significant differences between mean completion times measured before and after respective condition tasks as indicated by the simple effects analysis ($p < .001$).

Table 2

Descriptive Statistics for Experiment 2

Condition		Age		Before interference completion time (s)		After interference completion time (s)	
	N	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control	41	19.05	2.13	26.02	21.00	27.90	26.94
Immediate interference	39	18.80	1.74	26.69*	15.78	23.26*	13.03
Delayed interference	40	18.83	1.34	34.80	33.98	36.63	50.86
Total	120	18.89	1.76	29.17	24.68	29.30	34.30

Note. This table displays the descriptive statistics of the final data used in Experiment 2, after initial data removals, and separated by condition.

* Significant differences between median completion times measured before and after respective condition tasks as indicated by the Mann-Whitney U test ($p < .05$).

Variable	Total		Positive				Neutral			
			Immediate PANAS		Delayed PANAS		Immediate PANAS		Delayed PANAS	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
PANAS analysis										
N =	72		20		17		17		18	
General positive	30.11	7.72	30.30	7.15	31.24	7.62	30.00	7.79	28.94	8.80
General negative	15.72	5.70	15.25	5.59	17.82	7.33	14.35	4.95	15.56	4.54
Joviality	22.44	7.20	23.35	5.82	22.82	7.38	23.53	7.24	20.06	8.35
Attentiveness	14.07	3.08	13.35[a]	2.66	15.65[a]	2.91	13.06[a]	2.56	14.33[a]	3.66
Sadness	6.85	2.82	7.60	3.60	6.47	2.48	6.88	2.96	6.33	1.88
Fatigue	9.19	3.92	10.05	4.07	8.12	3.77	9.94	3.94	8.56	3.87
Surprise	6.40	2.75	6.30	3.03	7.59	2.87	5.47	2.35	6.28	2.45
Practice analysis										
N =	62		17		17		14		14	
Practice 2 CT	19.23	9.96	19.82[b]	12.64	20.18[b]	11.87	19.64	7.63	15.36	3.50
Practice 3 CT	16.47	5.49	15.06[b]	3.67	16.06[b]	4.44	18.50	7.50	16.14	5.20
Equation fit (*r*)	.75	.17	.75	.18	.79	.13	.75	.16	.71	.20
Practice 2 change	-0.39[c]	0.73	-0.46	0.48	-0.45	0.65	-0.23	0.19	-0.18	0.77
Practice 3 change	-0.25[c]	0.48	-0.30	0.32	-0.29	0.43	-0.15	0.13	-0.12	0.52
Practice 4 change	-0.18[c]	0.36	-0.22	0.24	-0.21	0.32	-0.11	0.09	-0.08	0.39
Test and transfer analysis										
N =	72		20		17		17		18	
First test CT	7.35	1.72	7.75	1.70	6.95	1.72	7.66	1.76	6.99	1.66
Second test CT	7.41	1.56	7.92[d]	1.55	6.99[d]	1.63	7.60	1.53	7.05	1.43
Transfer test CT	98.13	70.48	99.74	69.24	108.99	91.68	110.11	69.16	74.77	46.19
Transfer test NM	36.12	15.45	39.80	16.68	37.06	13.17	37.77	19.27	29.61	10.44

Note. This table displays the descriptive statistics of the final data used in each Experiment 3 analysis, after initial data removals, and separated by condition. PANAS = positive and negative affect schedule; CT = completion time (s); NM = total number of moves.

[a] Attentiveness, as measured by the PANAS, was higher in the Delayed PANAS conditions compared to the Immediate PANAS conditions ($p < .05$).

[b] CT of practice trials two and three were different within the Positive groups ($p < .005$).

[c] The rate of change was significantly different across practice trials two, three, and four ($p < .001$).

[d] Second test CTs significantly differed between the Immediate and Delayed PANAS groups ($p < .05$).

Figure 1

Tower of Hanoi Puzzle

Note. The Tower of Hanoi is a wooden puzzle that involves moving a stack of discs, one at a time, from a starting peg (the left peg in this image) to a target peg (the right peg in this image). There are specific rules to follow: only one disc can be moved at a time, and a larger disc cannot be placed on top of a smaller one. To complete the tower with four discs, it takes a minimum of 15 moves. The first step is to place the smallest disc on the middle peg (see Karwath, 2005). The rules determine this choice. The next move is to put the smallest disc on the right peg, which creates space for moving the second largest disc to the middle peg. After building a three-disc tower on the middle peg, it becomes possible to move the largest disc to the target peg on the right. Then, participants can rebuild the tower on the target peg.

Figure 2

Ring Puzzles

Note. A ring puzzle is typically a metal piece bent into a ring-like shape and linked with another piece. They are solved by twisting, sliding, or pulling the pieces apart.

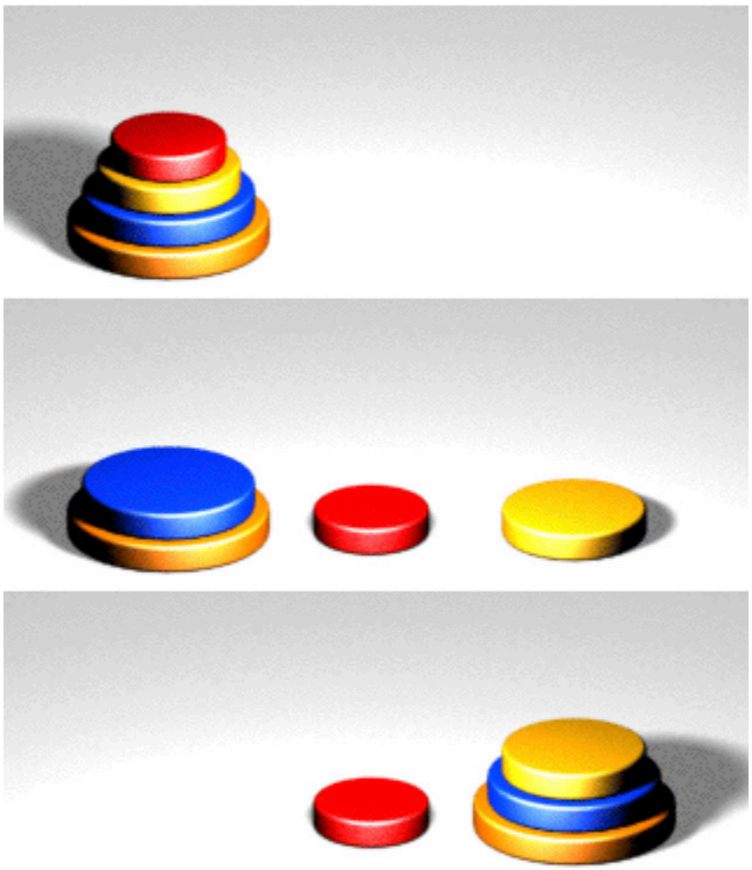
Figure 3

Peg Puzzles

Note. The left panel shows a peg puzzle requiring all pegs to switch sides. The center panel illustrates an elimination peg puzzle involving the removal of pegs from play by jumping one over another to an open spot. The right panel exhibits a peg puzzle requiring all holes but one to be filled by starting in any position and then tracing preset lines between holes.

Figure 4

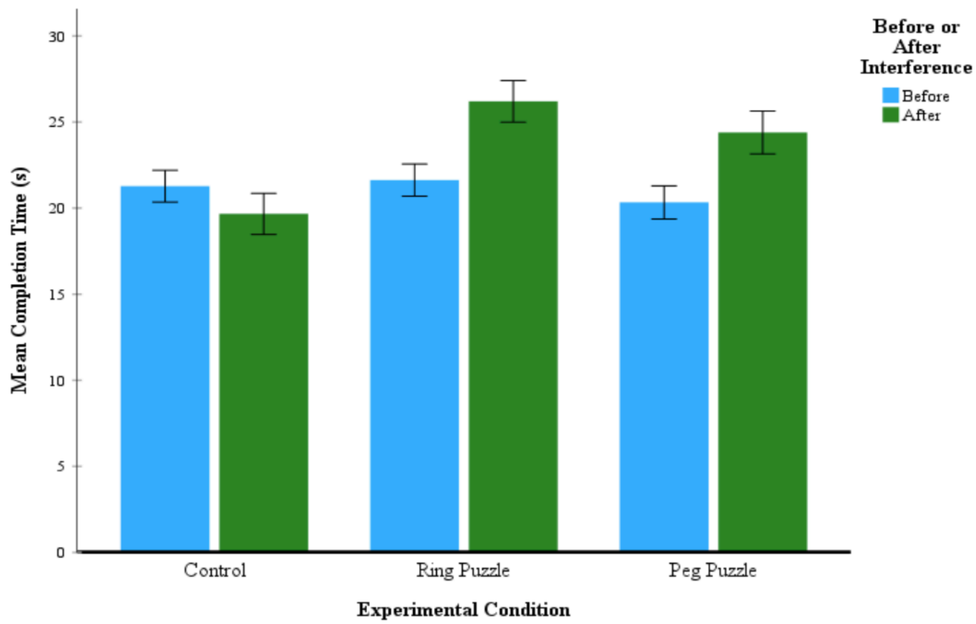
Animated Procedure for Solving the Tower of Hanoi



Note. Three slides from the digital .gif designed by Karwath (2005) illustrate an animated procedure for copleting the Tower of Hanoi puzzle with 4 discs.

Figure 5

Tower of Hanoi Completion Times Before and After Interference



Note. Experiment 1 Tower of Hanoi completion time (s) before and after interference in the control, ring puzzle, and peg puzzle groups. Error bars denote one standard error around each mean.

Figure 6

Procedural Sequences in Experiment 3

C1: PANAS → Learning → Pre-test → Waiting → Post-test → Transfer

C2: Learning → Pre-test → PANAS → Post-test → Transfer

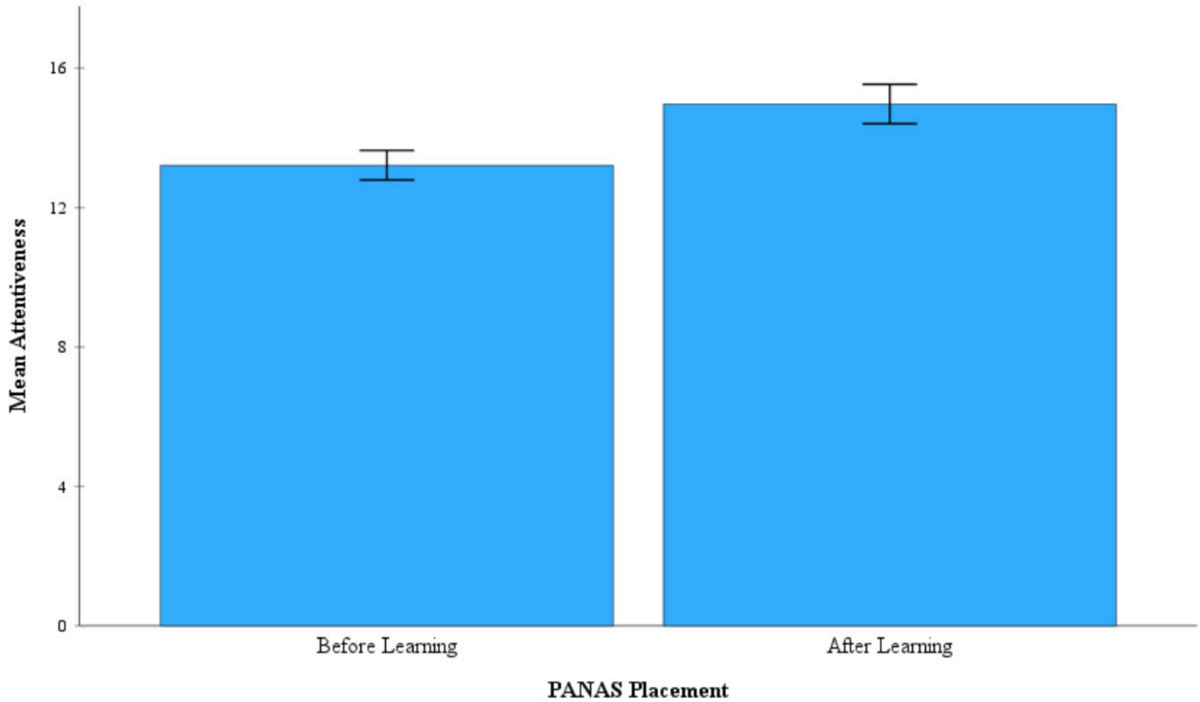
E1: Unexpected Reward → PANAS → Learning → Pre-test → Waiting → Post-test → Transfer

E2: Learning → Pre-test → Unexpected Reward → PANAS → Post-test → Transfer

Note. Experiment 3 procedures for each group respectively highlight differences in placement and affective tone. C = control; E = experimental; PANAS = positive and negative affect schedule expanded form.

Figure 7

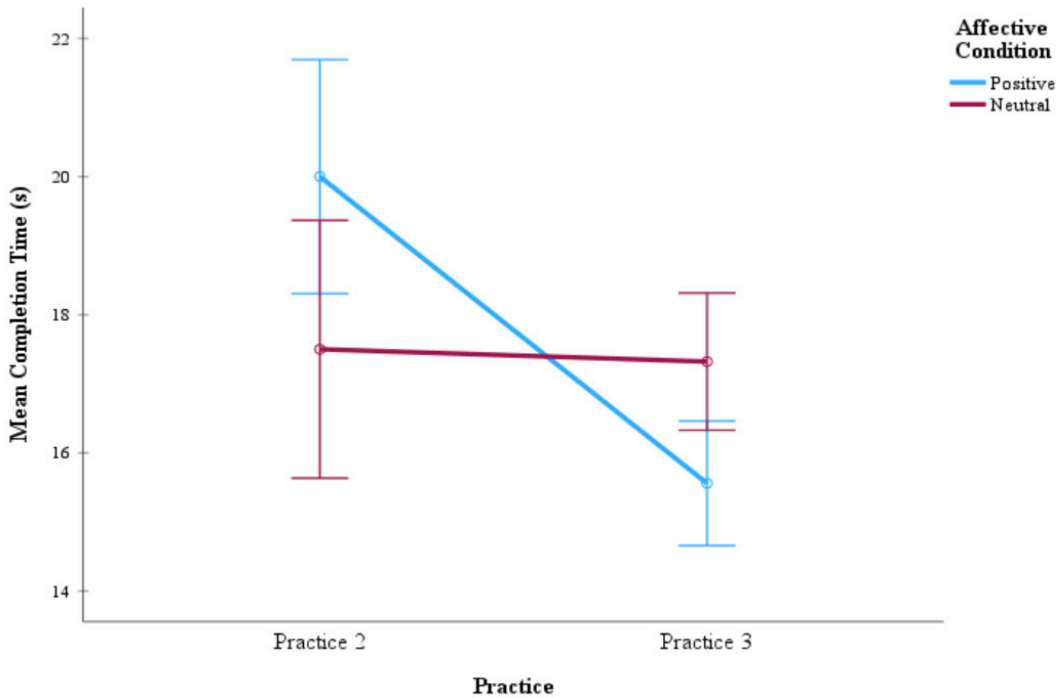
Attentiveness Before and After Learning the Tower of Hanoi



Note. Experiment 3 self-reported attentiveness measured before and after learning the Tower of Hanoi. Error bars denote one standard error around each mean.

Figure 8

Tower of Hanoi Completion Times Before and After Affect Induction



Note. Experiment 3 practice trial completion time measured at practice two and practice three, separated by affective condition. Error bars denote one standard error around each mean.