Examining the Proactive and Retroactive Placement of Augmented Information for Learning a Novel Computer Alphabet

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The timing of augmented information, either prior to or following a memory retrieval attempt has profound, and opposing, influences on immediate performance and retention. This effect was investigated in 2 experiments in which participants learned typographical symbols used to enter information into a personal data assistant. The effects of the spacing of the second of 2 repetitions (Experiment 1) and the number of retrieval attempts during practice (Experiment 2) failed to modify the relative effectiveness of the timing of augmented information—proactive information (prior to retrieval attempt) facilitated practice but degraded retention relative to retroactive information (after retrieval attempt). The theoretical roles of the timing of augmented information relative to the functions of retrieval practice were discussed.

Keywords: learning, practice, human-computer interaction, augmented information

Learning, at least with regards to the acquisition of motor skills, is highly dependent on instruction and feedback. In many ways instruction and feedback are complementary terms—both involve procedures that serve to augment the learner’s movement-related knowledge with external sources of information. Traditional use of augmented information as an instruction tool employs techniques such as demonstrations and is provided prior to the learner’s attempt at the task. This is defined as proactive augmented information because it occurs before an attempted action and provides information to the learner regarding what to do (Richardson & Lee, 1999). Feedback, however, is augmented information that is typically provided after the learner’s performance, often in the form of KR (knowledge of results). Richardson and Lee termed this retroactive augmented information because it occurs after an action and provides information about what was done.

The comparative roles and effects of proactive versus retroactive augmented information are often considered an “apples versus oranges” debate. Because the paradigms and methods used to investigate instruction and feedback effects have varied so widely, their direct comparison has not seriously been considered as an issue for inquiry (see Adams, 1986, for an exception). And because these types of augmented information have been studied as distinct lines of research, there have been few attempts to compare their relative effectiveness in facilitating the learning process. The goal of our research agenda is to examine the relative effects of augmented information when presented immediately before, or after, an action to-be-learned. What sets the current research apart from traditional methods in which augmented information is presented before (as in modelling research) or after (as in the KR literature) is that here the augmented information is identical in content and precision—only the timing of its presentation differs.

Two previous studies suggest that proactive timing of augmented information has strong guidance effects during practice that facilitate the acquisition of actions, at least for immediate performance benefits. In Richardson and Lee (1999), participants learned to produce handshapes corresponding to letters of the American Sign Language. On each trial during practice, the to-be-learned handshapes were presented either before a practice attempt (proactive), or immediately after the attempt (retroactive). Although the proactive schedule produced immediate advantages and near perfect performances, it was the retroactive schedule that resulted in better retention tests later the same day and after 48 hr. Patterson and Lee (2005) replicated these findings using a different task—learning to produce actions on a PDA (personal data assistant) that corresponded with English letters. The present paper reports two experiments designed to examine whether two common treatment effects (spacing of repetitions and number of repetitions) alter the relative effectiveness of proactive and retroactive augmented information.

Our previous research with learning handshapes and PDA script can be considered motor analogues of paired-associate list learning. A search of the paired-associate literature only revealed one related study that examined comparable proactive and retroactive style learning methods. Research by Cunningham and Anderson (1968) revealed that participants who were afforded the opportunity to view a stimulus cue (a two-digit number) together with its associated response (a consonant-vowel-consonant [CVC] trigram) before spelling the CVC demonstrated superior recall compared to a group of participants who were shown the CVC after an attempted retrieval of the response. This finding is similar to the benefits of proactive augmented information seen during acquisition trials in our previous experiments. However, Cunningham and Anderson only examined recall after a 30-s delay following the last training trial. Thus it is unknown whether the retroactive study
method would have resulted in superior CVC recall after a longer-term delay period, as would be predicted by our previous results.

The strong performance effects of a proactive augmented information schedule during acquisition trials, but poor learning effects as seen in retention, resonates with a number of findings in both the motor and verbal learning literature. In motor learning, an abundant literature on the contextual interference effect has demonstrated that blocked (or drill-type) practice facilitates immediate performance gains, but is inferior to random ordering of practice when retention and transfer are measured (Magill & Hall, 1990; Shea & Morgan, 1979). Contextual interference effects have also been found in the learning of cognitive skills, such as logic rules (Carlson & Yau, 1990) and foreign language vocabulary (Schneider, Healy, & Bourne, 2002), indicating that these phenomena might reflect general features about learning.

The effects of proactive and retroactive augmented information schedules and contextual interference effects on learning are also consonant with Bjorj’s (1988, 1994) ideas on the costs and benefits of introducing desirable difficulties into the learning environment. Methods such as random practice introduce impedances to the easy acquisition of material that forces the learner to undertake more effective cognitive operations to better retain the information. The costs for these increased effortful processes are performance tradeoffs in the short-term, but long-term benefits as seen in enhanced retention and transfer, relative to less-difficult practice conditions (see also Roediger & Karpicke, 2006).

What types of processes might be influenced by these desirable difficulties? One suggestion is provided in recent research by Kronlund and Whittlesea (2006), who found that perceptual discrepancies have long-lasting effects in stem-completion experiments. In their experiments, Kronlund and Whittlesea found that a temporal delay between reading a sentence stem and viewing a specified target word resulted in the development, and then resolution, of uncertainty. The introduction of uncertainty into the study phase may be seen as a specific type of desirable difficulty, which, after being resolved, resulted in enhanced memory in a later test. This finding may help to understand our previous work in that the creation of uncertainty, followed by the resolution of it, is inherent in the proactive augmented information schedule. In contrast, no uncertainty exists in the proactive schedule because the relevant information is presented prior to any retrieval operations.

The two experiments reported here assessed whether the effects of proactive and retroactive augmented information are differentially influenced by either the spacing of repetitions during practice (Experiment 1) or the total amount of physical practice (Experiment 2). Theoretically, the guiding role of proactive augmented information was expected to diminish if presented in either a more cognitively demanding spaced practice schedule (e.g., Cuddy & Jacoby, 1982) or when presented less frequently (Schmidt & Bjork, 1992).

### Experiment 1

In Experiment 1 we compared retroactive and proactive information schedules with two types of spacing of repetitions during the practice period. Individuals were provided eight practice trials with each of the PDA characters—the key variable being the spacing of every second practice trial. One subgroup of individuals within both the proactive and retroactive groups practised every second repetition of the PDA character immediately after the previous trial (lag = 0).

Another subgroup of individuals within each group was provided the second repetition of the PDA character after five intervening trials involving different PDA characters had been practised (lag = 5).

Research on the spacing effect in memory for cognitive items for younger adults (e.g., Bjork & Allen, 1970; Cuddy & Jacoby, 1982; Melton, 1967; Pashler, Zarow & Triplett, 2003), older adults experiencing healthy ageing and persons with mild dementia of the Alzheimer type (Balota, Duchek, Sergent-Marshall, & Roediger, 2006), and similar effects for motor skills learning (Donovan & Radosевич, 1999; Lee & Genovese, 1988), suggests that cognitive effort serves an important mediating role in retention. According to Bjork (1988), the act of retrieval not only strengthens the memorability of the item, but also facilitates the cognitive processes required for skillful retrieval. Therefore, we predicted that the spaced repetitions would induce more cognitive effort for the individuals provided with proactive augmented information, and thereby enhancing retention of the PDA symbols.

A second variable that was predicted to interact with the temporal provision of augmented information was the nature of the PDA items to-be-learned. Previously, we found that PDA characters ranged widely in similarity to their English referents and subsequently, empirically established three subsets of items differing in compatibility (Patterson & Lee, 2005). In a meta-analysis by Donovan and Radosевич (1999), task complexity was found to be a key moderator of the spacing effect, such that tasks high in complexity (e.g., air traffic controller simulation; hand movement memorisation) were associated with smaller mean differences between spaced and massed practice conditions compared to simpler motor tasks. A similar finding for the learning of motor skills suggested that cognitively effortful random practice conditions were most beneficial for tasks of lower to moderate difficulty (Albaret & Thon, 1998; see also Guadagnoli & Lee, 2004). We predicted that the degree of complexity of the PDA items would interact with both the temporal placement of augmented information (e.g., either proactive or retroactive) and the spacing of items during practice (lag = 0 or lag = 5). Specifically, based on the results of Patterson and Lee, we predicted that participants who were presented information retroactively and afforded the opportunity to retrieve the updated motor plan (e.g., lag = 0) would show superior learning of the PDA items of high, moderate, and low complexity compared to the retention performance of the proactive and retroactive groups experiencing a temporal delay of 5 intervening trials. To test our experimental predictions we had participants perform immediate (10-min) and delayed (2-day) retention tests that withheld all augmented information. This method of relying on retention tests as the primary measure of learning is consistent with standard motor learning experiments of this type in which manipulations in the practice context result in transient boosts in practice performance (see Schmidt & Lee, 2005, chapter 10, for an expanded discussion).

### Method

**Participants.** Twenty-eight right-handed participants (14 male, $M = 22.4$ years, 14 female, $M = 23.1$ year) from McMaster University participated in the study. All were screened prior to their participation to ensure none had ever used a PDA or had any knowledge of the Graffiti language. All participants provided informed consent and were naive to the purposes of the experiment. They were paid $15.00 on completion of the experiment.
Apparatus. The experimental apparatus and set-up were identical to Patterson and Lee (2005). Two computers were used to conduct the experiment. One computer monitor, located directly in front of the participant, displayed a PDA simulator—a computer program that simulated the operations of a PDA. The PDA simulator was displayed on a 38-cm colour monitor, located approximately 60 cm from the participant, on a 31-cm × 31-cm base that was elevated 17 cm above a standard desk. The PDA simulator operated on a 486-64MB computer. The PDA simulator had a visual display of 20 cm (length) × 14.5 cm (width). Participants interacted with the PDA simulator using a wireless Intuos Stroke and Inking Pen (similar to the size of a standard pen) on a 30 × 46 cm WACOM digitising graphics tablet, serially connected to a second computer. A rubber border surrounded an 11-cm × 5.5-cm writing space on the graphics tablet. The size of the experimenter-defined writing space corresponded exactly to the size of a 6.5 × 4 cm PDA simulator writing area, displayed in the lower half of the PDA simulator.

Each trial started from a circular (1.5 cm × 1.5 cm) “home” button, located approximately 5 cm below the centre of the defined writing space on the graphics tablet. This home button was connected serially to the data collection computer and interacted with the E-prime data acquisition program that presented various experimental events and recorded aspects of the participant’s responses. The E-prime program was customised to present a series of digital images to participants, one above the other, for a total 9.5 cm × 7 cm display size located in the centre of the second computer monitor (having 43 × 43 cm dimensions), which was elevated similar to that of the other monitor. To produce characters of the English script in the PDA, the user is required to enter a PDA script equivalent. The PDA script is a unique collection of symbols that vary in spatial and motor similarity to the English-script referent (see Figure 1). The degree to which an environmental cue (e.g., PDA character) corresponds to the conceptual association already existing as a mental code in the performer (e.g., English script character) has been termed conceptual compatibility (Sanders & McCormick, 1993). Some PDA characters closely resemble the English script [for example, the ‘’ symbol], whereas other PDA characters are conceptually and motorically very different (e.g., the ‘‘ symbol). The stimulus display consisted of three English-PDA pairs of the same compatibility (e.g., high, moderate, low) from Patterson and Lee (2005). The left side of the stimulus display consisted of three English symbols, one above the other; the right side consisted of the associated PDA symbols. As illustrated in Figure 1, to produce a specific PDA symbol required two separate motor actions. The start point of each tracing is identified by a filled circle in Figure 1. The first motor response required the participant to produce either a backslash or simply tap the digitising tablet once before producing the subsequent second symbol. Correct completion of both tracings was required to produce the appropriate PDA symbol.

Procedure. Participants were run individually through the experimental protocol and completed a total of 8 repetitions of each triplet presentation (i.e., each screen presented three English-PDA pairs of high, moderate, or low compatibility). Individuals practiced two different triplets of each of the three compatibility types, eight repetitions each, for a total of 48 acquisition trials. The practise session lasted approximately 45 minutes. The four acquisition groups consisted of a factorial combination of two independent variables: (a) the temporal placement of the augmented information in a practice trial—either before (proactive) or after (retroactive) the cursive actions, and (b) the spacing of repetitions of the identical trials—two repetitions of the same triplets were either presented in immediate succession (i.e., lag-0) or in a spaced practice order (lag-5).

The preexperimential protocol began with a series of instruction screens, followed by a series of practise trials writing PDA symbols not used in the experimental protocol. The PDA symbols were written with a digitizing pen in the defined writing space on the tablet, interacting with a PDA simulator. Participants then performed three practice trials according to the experimental protocol to which they had been assigned and were encouraged to ask questions to clarify the methods.

Participants in the lag-0 groups practised the same PDA symbols on two consecutive trials before practising different PDA symbols of a different compatibility in a subsequent trial. For the lag-5 repetition

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Figure 1. Examples of PDA symbols categorised as high, moderate and low compatibility from Patterson & Lee (2005).
schedule, participants experienced a delay of five intervening trials before completing a repetition of any given PDA symbol.

A typical trial in the proactive lag-5 condition required participants to study a display of three English-PDA pairs for a self-determined amount of time until verbally indicating to the experimenter they had memorised the triplet. The stimulus display was removed immediately and followed by the presentation of only the three English referents, in the same order as previously presented. On viewing these recall cues, participants attempted to reproduce the corresponding PDA symbols on the digitising tablet, interacting with the PDA simulator. After writing their responses the participants returned to depress the home button to complete the trial. Participants received visual feedback (i.e., the display of their tracings) together with verbal feedback (“correct” or “incorrect”) regarding the success of their tracings. Participants then completed in immediate succession, the tracings of the other five English-PDA triplets, before the previously studied triplet was practised again. The proactive lag-0 condition differed from the lag-5 group in that the second of two consecutive trials was conducted immediately after the first (see Figure 2, for an illustration of the experimental protocol).

A typical trial for the retroactive lag-5 condition began with participants first viewing three English referent (recall) cues without the corresponding PDA symbols. After viewing this display for a self-determined amount of time, participants lifted the stylus from the home button (completing the RT period) and attempted to produce the corresponding PDA symbols. Once completed, the participants returned to the home button to complete the response. Participants were then presented the complete triplet of English-PDA pairs for a self-determined amount of time and received visual and verbal feedback regarding the success of their tracings. Participants then attempted to produce the other five triplets. Participants in the retroactive lag-0 group repeated the just-completed trial for a second time before attempting a different triplet.

It is important to note that the first trial for both retroactive groups required participants to guess their initial motor responses for the PDA symbols to the English referents because the initial provision of augmented information did not occur until after the completion of the first motor response.

Learning was examined in two retention tests: one administered 10 minutes after the completion of the last acquisition trial and the other 48 hr later. Retention was a cued-recall test in which participants attempted to write the PDA symbol that corresponded to a single English referent. Participants were required to produce nine different PDA symbols (3 high, 3 moderate, and 3 low compatibility symbols) in the immediate and delayed retention tests, counterbalanced across participants. Augmented information was withheld in the retention tests.

Results and Discussion

Data analyses. The dependent variable of recall fluency was used to measure performance for the acquisition and retention period. Recall fluency was the proportion of PDA characters that were successfully performed when cued. To capture recall fluency, a numeric value of “1” or “0” was entered, dependent on which of three possible outputs were automatically generated by the PDA simulator. First, if the produced symbol was performed correctly, the required English symbol was displayed on the PDA simulator and the experimenter entered a 1. If the motor action was performed incorrectly but similar to that for a different English symbol, then that English symbol was displayed, indicating an incorrect response and the experimenter entered a 0. If the motor action was performed incorrectly and did not otherwise correspond to a known character, then no symbol was displayed and the experimenter entered a 0 for that trial. The recall fluency of the PDA symbols was recorded in the acquisition and retention period of the experiment.

**Figure 2.** Typical trial for Experiment 1 conditions.
The interactive effects of information location and repetition type on acquisition recall as a function of PDA item compatibility was determined by analyses of variance conducted on recall performance data using a 2 (information location: proactive, retroactive) × 2 (repetition: lag-0, lag-5) × 3 (compatibility: high, moderate, low) × 8 (blocks of trials) model with repeated measures on the last two factors. The analyses of the recall in the retention tests were conducted using a 2 (information location: proactive, retroactive) × 2 (repetition: lag-0, lag-5) × 3 (compatibility: high, moderate, low) × 2 (block; immediate, delayed retention) analysis of variance (ANOVA) model with repeated measures on the last two factors. A significance level of \( p < .05 \) was used for all statistical tests. Post hoc comparisons were conducted using a Tukey’s HSD.

**Acquisition.** The recall success is depicted on the left side of each panel in Figure 3. The ANOVA revealed main effects for information location, \( F(1, 24) = 29.21, \text{MSE} = 0.37, p < .05 \); repetition type, \( F(1, 24) = 5.08, \text{MSE} = 0.37, p < .05 \); block, \( F(7, 168) = 47.11, \text{MSE} = 0.03, p < .05 \); and symbol compatibility, \( F(2, 48) = 47.02, \text{MSE} = 0.07, p < .05 \). The main effects were superseded by a series of two-way interactions: an Information Location × Block Interaction, \( F(7, 168) = 13.22, \text{MSE} = 0.03, p < .05 \); a Repetition Type × Block Interaction, \( F(7, 168) = 5.79, \text{MSE} = 0.30, p < .05 \); and an Information Location × Symbol Compatibility Interaction, \( F(2, 48) = 8.82, \text{MSE} = 0.07, p < .05 \). More important, the two-way interactions were superseded by an Information Location × Repetition Type × Block Interaction, \( F(7, 168) = 5.34, \text{MSE} = 0.03, p < .05 \).

The Tukey post hoc analysis of the three-way interaction revealed that for Blocks 1, 3 and 5, the proactive groups demonstrated superior recall compared to the retroactive groups. For Blocks 2, 4, 6 and 8, the retroactive lag-0 group demonstrated recall levels that were equivalent to the proactive lag-0 and proactive lag-5 groups, and collectively, superior to the retroactive lag-5 group. These findings suggest the spacing of repetitions impacted the proactive and retroactive conditions differently. For the proactive conditions, the recall performance was independent of the spacing of the repetitions (lag-0 or lag-5). More important, however, when participants in the proactive lag-0 condition were afforded the opportunity to utilise the information from the previous trial (even numbered blocks), their recall success was similar to both proactive conditions and superior to the retroactive lag-5 condition, suggesting these participants were bypassing the effortful, less successful retrieval processes required by the retroactive lag-5 condition.

**Retention.** The initial analyses of the retention data indicated that the between-participants independent variables (information location and repetition type) did not interact for recall fluency, \( F(2, 48) = 0.67, \text{MSE} = 0.04, p > .05 \); power = 0.16. There was a main effect for information location, \( F(1, 24) = 13.62, \text{MSE} = 3.15, p < .05 \); however the main effect for repetition type did not approach statistical significance, \( F(1, 24) = 1.03, \text{MSE} = 0.24, p > .05 \). Therefore, the lag-0 and lag-5 groups were collapsed into two between-participants groups (proactive/retroactive). A series of Group × Symbol Compatibility × Block (immediate, delayed) ANOVAs with repeated measures on the last two factors were performed on the retention data.

Proportions of correctly recalled symbols are presented in the right side of each panel in Figure 3. The ANOVA revealed a main effect for information location, \( F(1, 26) = 14.12, \text{MSE} = 0.22, p < .05 \), and symbol compatibility, \( F(2, 52) = 20.77, \text{MSE} = 0.07, p < .05 \). Overall, the retroactive groups (\( M = .75 \)) demonstrated higher recall than the proactive group (\( M = .46 \)), and that high compatibility symbols (\( M = .84 \)) were recalled more successfully than the moderate (\( M = .49 \)) and low compatibility symbols (\( M = .50 \)).

Spaced practice was predicted to have facilitated retention in the proactive groups because repetitions were spread out more evenly during the practice trials (Bjork & Allen, 1970; Cuddy & Jacoby, 1982; Donovan & Radosevich, 1999; Lee & Genovese, 1988; Pashler et al., 2003). However, the results did not support this prediction. The absence of a beneficial spacing effect for the proactive group may be due to the preemptive role of the augmented information on the retrieval processes of the performer, regardless of the lag size between successive repetitions. Conversely, paired repetitions were predicted to diminish the effectiveness of the retroactive conditions because the second of two consecutive trials could be performed with the information from the previous trial still in working memory. Again, this prediction was not supported. The rationale for the failure of this latter prediction is not entirely clear, although Figure 3 does provide a clue to what might have occurred. Remember that the protocol involved eight study/recall trials of each English/PDA pair, and the lag manipulation occurred between the first and second of two consecutive trials. It could be the case that only the first of the two consecutive trials was necessary to support sufficient retrieval practice to facilitate retention. The acquisition data in Figure 3 clearly illustrates that the first of two consecutive trials (i.e., Trials 1, 3, 5, and 7) in the retroactive lag-0 group performed much more poorly than the second of two consecutive trials (i.e., Trials 2, 4, 6, and 8). Thus, between the second of two trials and next retrieval of that item, there was sufficient loss of information from working memory. The participants were required to attempt to retrieve the information from memory, effortful and with less success, than on the second of two trials. In essence then,

![Figure 3](image-url)
perhaps the second repetition in a lag-0 condition did not provide an additive benefit for retention.

In sum, the superior performance benefits during practice for the proactive groups, reversed in retention by superior performance for the retroactive groups, replicate previous findings by Richardson and Lee (1999) and Patterson and Lee (2005). The role of PDA-English similarity and the spacing of the second of two repetitions only had a moderating impact on the influences of proactive/retroactive conditions during practice trials. A recent pair-associated learning task comparing young adults, older adults, and older adults with mild dementia of the Alzheimer type also found no differences between an expanded retrieval practice schedule (e.g., expanding the retrieval interval on a successful response, decreasing the retrieval interval on an incorrect response) and an equal interval spacing of retroactively placed augmented information (Balota et al., 2006) for retention of the word pairs. Contrary to expectations regarding the moderating role of practice conditions in motor learning, based on empirical grounds (Albaret & Thon, 1998) and theoretical arguments (Guadagnoli & Lee, 2004), the spacing factors had no impact on the proactive/retroactive effects in retention.

A question in this research agenda that remains unresolved concerns the specific role of physically attempting to produce a PDA character in response to an English cue. These experiments (Patterson & Lee, 2005; Richardson & Lee, 1999; and Experiment 1 here) confounded the cognitive role of “retrieval practice” (Bjork, 1988) and the motor role of producing the retrieved item. Clearly, the proactive conditions undermine the putative role of the cognitive component, but perhaps not so the motor component. Having the solution (i.e., the PDA character) presented to the participant just prior to the cued response reduces (or eliminates) the effort required to retrieve the correct PDA character from memory, compared to the requirements of the retroactive conditions. Nevertheless, the motor component involved in producing the correct cursive hand strokes on the PDA are no less involved in the proactive than in the retroactive condition. In fact, there is likely to be more motor practice involved for the proactive condition than the retroactive condition because more PDA characters are recalled correctly during the practice trials in the proactive condition. In the following experiment, we attempt to isolate the roles of cognitive and motor practice by using a partial recall paradigm.

Experiment 2

The goal of the present experiment was to examine the relative contributions of the cognitive and motor components of learning under proactive and retroactive practice conditions with varying amounts of overt physical practice of the PDA symbols. In Experiment 1, participants attempted to recall all of the cued PDA characters on each trial. In Experiment 2, we used a partial, cued recall paradigm to dissociate the effect of the number of times that an item was studied from the number of times that its retrieval was attempted. Each trial involved studying a four-pair display, with each of six different displays repeated 13 times over the practice session. However, only one of the four characters was cued for recall on any particular trial. Across the practice session, a specific character was cued for recall on 8, 4, 1 or none of the 13 repetitions. By using this partial cued-recall paradigm, we sought to unconfound the relative contributions of studying all of the English-PDA characters on 13 separate occasions from the impact of attempting to recall any particular PDA character on 8, 4, 1 or 0 of the trials during practice.

For the retroactive conditions, it was predicted that the differential number of recall attempts would have a large impact on the cognitive component during practice. Given the argument that cognitively effortful practice is beneficial for learning, and that the proactive information schedule produces considerable effort in retrieval, then increasing the number of effortful retrieval attempts should be increasingly beneficial to retention. In contrast, the proactive conditions were expected to reveal minimal impact of increased repetitions. Because the proactive group is provided the PDA “solution” immediately prior to its attempted recall, there is minimal cognitive effort required when an item is cued for recall. Thus, the benefits of additional practice attempts should have little impact on retention because effortful retrieval is minimised during acquisition.

On the other hand, the opposite prediction can be made from a motor perspective (e.g., Adams, 1971; Schmidt, 1975). From this perspective, successful retrieval of the correct PDA character is more likely to result from increased number of practice attempts in the proactive condition—more successful retrievals should produce more correct actions in producing the correct PDA character. Thus, for the proactive condition, increasing the number of attempted retrievals should benefit retention. The retroactive condition was not expected to show a similar effect. The probability of successfully retrieving the correct symbol from memory is low (especially for moderate and low compatibility symbols; see left side of panels in Figure 3). Therefore, from a motor execution view, successfully completing the motor action was less likely to impact the proactive groups in retention, regardless of the number of attempted recalls.

Method

Participants. Thirty-two participants (16 male, $M = 20.8$ years, 16 female, $M = 22.3$ years), all self-declared right-handed from McMaster University volunteered to participate in the study. All participants were screened prior to their participation to ensure none had ever used a PDA or had any knowledge of the PDA symbols. All participants were naïve to the purposes of the research, provided informed consent before participating and were paid $15.00 on completion of the experimental protocol. None were participants in Experiment 1.

Apparatus. The experimental apparatus was identical to Experiment 1. All of the English-PDA pairs from Experiment 1 were included here. However, a fourth English-PDA pair, selected from the sets identified in Patterson and Lee (2005), was added to each of the high, moderate and low compatibility displays.

Procedure. Compared to Experiment 1, the main difference in the methods used here was the nature of the cued-recall task. In Experiment 1, the participants performed a full cued-recall task—three pairs of English-PDA characters were studied and recalled. In the present experiment, we used a partial cued-recall task—although four pairs of English-PDA characters were studied on each trial, only one English character was presented for cued recall. In this manner, the number of trials that each four-pair display was studied (13) was dissociated from the number of recall attempts that were made for each item within the display (8, 4, 1, or 0).

As in the previous experiments, participants were randomly assigned to one of two groups (n = 16) that received task-related
augmented information either before (proactive) or after the attempted recall (retroactive). Participants completed two experimental sessions: one session of acquisition and retention, and one session examining long term retention of the PDA symbols (approximately 48-hr after the final practice trial in acquisition).

All of the English-PDA pairs were completely counterbalanced across participants within each group, such that a specific item selected for study and recall eight times for one individual, would be selected for four, one, or zero study/recall attempts for three other participants within each group. There were six, four-pair English-PDA displays—two representing high, moderate and low compatibility pairs. The six displays were presented in blocks of six trials, repeated 13 times each, for a total of 78 trials in acquisition. Each display contained four pairs, but only one was cued for recall on each trial. The specific PDA symbols from each of the six different displays that were cued for recall eight times during the acquisition trials were cued on Trials 1 to 6, 7 to 12, 13 to 18, 19 to 24, 31 to 36, 43 to 48, 55 to 60, and 67 to 72. The PDA symbols physically practised four times were cued on Trials 25 to 30, 37 to 42, 49 to 54, and 61 to 66. The PDA symbols practised only once during the acquisition period were cued on Trials 73 to 78. And, of course, the six PDA symbols not physically practised during the acquisition period were never cued for recall during the acquisition trials.

In summary, for each four-pair display that was studied on 13 occasions, one specific character was studied and cued for recall on 8 trials, and studied but not cued for recall on 5 trials. Another character from the display was studied and cued for recall on 4 trials, and studied but not cued for recall on 9 trials. A third character from the display was studied and cued for recall on only 1 trial, and studied but not cued for recall on 12 trials. And a final character was studied on 13 trials, but never cued for recall. Our goal was to examine whether the timing of presenting augmented information during the study period, either before or after a recall attempt, had a differential effect on learning based on the number of times an item was cued for recall (see Figure 4 for an example of a typical trial for each experimental condition).

Cued retention tests were administered 10 minutes and 2 days after the completion of the last acquisition trial. In each retention test, participants produced one PDA symbol, in response to a visual cue (English script prime) that had been practised eight, four, one and zero times during the acquisition period from each of

![Typical Trial for Proactive Group](image1)

![Typical Trial for Retroactive Group](image2)

Figure 4. Typical trial for Experiment 2 conditions.
the three compatibility categories (high, moderate, and low) for a total of 12 different PDA symbols being cued for recall in each retention test. The items selected for immediate versus delayed recall were counterbalanced across participants. Similar to Experiment 1, participants were required to motorically produce the correct PDA symbol in response to a cued recall prime.

Results and Discussion

Data analysis. Because the English-PDA pairs received an unequal number of trials during practice (and some with no data at all), we have focused our analysis only on the retention data. The recall success data were analysed separately in an Information Location (proactive, retroactive) × Retention Test (immediate, delayed) × Symbol Compatibility (high, moderate, low) × Number Of Physical Practice Trials in the acquisition period (8, 4, 1, and 0) ANOVA, with repeated measures on the last three factors.

The proportion of PDA characters recalled correctly in retention revealed four main effects and one interaction. Overall, the retroactive augmented information group correctly recalled more items (M = .78) than the proactive group (M = .70), F(1, 30) = 4.70, MSE = 0.31, p < .05. As well, the pairs that were physically practised 8 times (M = .78) and 4 times (M = .80) during acquisition were recalled better than the pairs physically practised once (M = .71) and not at all (M = .67), F(3, 90) = 3.85, MSE = 0.19, p < .05. It is interesting to note that there was no significant difference between the latter two means. Highly compatible English-PDA pairs (M = .86) were recalled better than moderate pairs (M = .69) and pairs of low compatibility (M = .68), F(2, 60) = 18.23, MSE = 0.15, p < .001. And, recall in the immediate retention test (M = .80) was higher than in the delayed retention test (M = .68), F(1, 30) = 18.42, MSE = 0.16, p < .001.

The only significant interaction was a Group × Retention Test Interaction, F(1, 30) = 5.21, MSE = 0.16, p < .05. The means for this interaction are illustrated in Figure 5. This interaction revealed that, although there was a significant reduction in recall success between the immediate and delayed retention tests for the proactive group, the retroactive group’s recall success was not significantly diminished after the 48-hr delay period.

In summary, the findings of the present study help to clarify and extend our understanding of the role of practice in learning to produce PDA character sets. More interesting, increased amounts of physical practice during the acquisition period facilitated the motor action of the PDA characters for the proactive and retroactive condition similarly during the retention period. However, once again, the findings revealed that PDA characters were successfully recalled more often following a proactive practice schedule than a proactive schedule. Moreover, the present experiment was the first in this series to show that proactive practice slowed the loss of retention in a delayed test, relative to proactive practice.

General Discussion

Augmented information has enjoyed the status as being one of the most powerful variables in the study of learning, particularly so in the motor learning literature (Magill, 2003; Salmoni, Schmidt, & Walter, 1984; Schmidt & Lee, 2005). The two most common forms of augmented information are models, which demonstrate to the learner “what to do,” and feedback, which tells the learner “what was done.” Of the two types, feedback is generally considered to be the more important, possibly attributed to its function in evaluating performance and devising strategies for improvements in performance using problem-solving (cognitive) and motor activities. Modelled information, though especially effective early in performance, is generally considered to be of limited usefulness, and certainly less effective than feedback in the learning process. Clearly, there are many differences in modelled and feedback information, including the amount of information contained and the time at which it is presented relative to a particular performance. Together with previous research (Patterson & Lee, 2005; Richardson & Lee, 1999), the present findings suggest that when the information content is equated, the timing of its presentation has a differential influence on learning.

Why do these differences exist? We argue that these effects relate to differences in what Bjork (1988) termed as “retrieval practice”—which suggests that the process of retrieval is a skill that, like other skills, becomes more efficient and effective with increased opportunities for practice (see Roediger & Karpicke, 2006, for review). In our studies, the proactive conditions were designed to provide no advanced information prior to an attempted retrieval. Although the absence of advanced information reduced performance measures during acquisition trials (especially so early in practice and for the low and moderate difficulty items), repeated practice in attempting to retrieve the associated PDA symbol produced a learning effect that was more effective and longer lasting (e.g., Experiment 2) than the proactive conditions. In contrast, the preresponse information provided to the proactive groups undermined the need to practice retrieval processes. Consequently, retention was relatively poor when retrieval was required following a delay interval (Experiment 2).

A fundamental assumption of the recently proposed challenge point framework (Guadagnoli & Lee, 2004) is that motor learning is a problem-solving process. To facilitate the problem-solving processes of the learner, task-related information presented to the performer must be presented in the most appropriate manner for efficient processing (Guadagnoli & Lee, 2004). However, when practice factors interact with task complexity to increase the cognitive demands of the performer, performance may suffer (Albaret & Thon, 1998). The results of Experiment 1 and 2 suggest that from the initial onset of practice, performers should be actively participating in the processes required for motor plan retrieval, such as those retrieval processes afforded by the proactive placement of augmented information.

In terms of practical application, these findings of the present studies help to clarify why feedback information is a more dominant factor in motor learning than modelled information. In instances of discrete, closed motor skills (e.g., a golf swing), a motor performance requires an individual to prepare an action in advance and to execute that action upon an internal go signal. The preparation process is an act of retrieval from memory of a movement plan, or motor program (Schmidt, 1975). Augmented (modelled) information that resides in working memory can circumvent the retrieval process. The present research suggests that a proactive information condition serves to circumvent the retrieval process by providing the relevant information in working memory at the time when a retrieval attempt is requested—thus, retrieval practice is undermined. Note however, that some augmented feedback conditions may work in the same way as well. When augmented
feedback is presented frequently, especially so under massed-practice conditions, then retrieval practice is also circumvented (Schmidt & Bjork, 1992). Instead, for augmented feedback conditions to be most effective, it must be presented in such a way as to not effectively “guide” practice attempts. That is, the information should be presented in such a way as to promote the practice of retrieval processes. Reduced feedback frequency, combined with variable practice conditions and orders, have been suggested as the most beneficial methods of promoting retrieval practice (Schmidt & Bjork, 1992). Generally, the present research lends further support to the postulations that suggest practice factors facilitating increased cognitive effort of the participant is essential for learning voluntary actions.

Résumé

Le moment de donner de l’information complémentaire sur une tâche de remémoration, que ce soit avant ou après la tentative de remémoration, a des incidences marquées et opposées sur la performance immédiate et la rétention de l’information. Ce phénomène a été étudié au cours de deux expériences pendant lesquelles les participants devaient apprendre les symboles typographiques utilisés pour saisir de l’information dans un personal data assistant (assistant numérique). Les effets de l’espacement de la dernière des deux répétitions (expérience 1) et le nombre de tentatives de remémoration pendant la phase d’apprentissage des symboles (expérience 2) n’ont pas réussi à modifier l’efficacité relative du moment de donner de l’information complémentaire; en revanche, l’information proactive (c.-à-d. avant la tentative de remémoration) a facilité l’apprentissage, mais elle a diminué la rétention par rapport à l’information rétroactive (c.-à-d. après la tentative de remémoration). Les rôles théoriques liés au moment de donner de l’information complémentaire par rapport aux fonctions de la phase d’apprentissage d’une tâche de la remémoration sont analysés.

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Received June 2, 2006
Accepted May 24, 2007